TRANSACTIONS
OF THE
AMERICAN GEOPHYSICAL UNION

Volume 12

1931

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Johnson Reprint Corporation
New York, New York

NATIONAL RESEARCH COUNCIL

TRANSACTIONS OF THE AMERICAN GEOPHYSICAL UNION
TWELFTH ANNUAL MEETING, APRIL 30 AND MAY 1, 1931
WASHINGTON, D. C.

Published by the National Research Council
of
The National Academy of Sciences
Washington, D. C.
June 1931

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INTRODUCTION

The American Geophysical Union is the American National Committee of the International Union of Geodesy and Geophysics, and the Executive Committee of the American Geophysical Union is the Committee on Geophysics of the National Research Council. The objects of the Union are to promote the study of problems concerned with the figure and physics of the Earth, to initiate and coordinate researches which depend upon international and national cooperation, and to provide for their scientific discussion and publication. In the accomplishment of these objects, the Union is divided into sections following the plan of organization of the International Union of Geodesy and Geophysics. There are now seven sections, namely, (a) Geodesy, (b) Seismology, (c) Meteorology, (d) Terrestrial Magnetism and Electricity, (e) Oceanography, (f) Volcanology, and (g) Hydrology. A Section of Geophysical Chemistry was discontinued May 31, 1924, as the International Union had failed to provide such a Section; the Section of Hydrology was established November 15, 1930--matters pertaining to scientific hydrology referred to the American Geophysical Union had been previously looked after by special committees on hydrology.

Annual assemblies of the Union and annual meetings of its sections for the discussion of reports and symposia are held each year. Thus far there have been twelve such assemblies and meetings, all held in Washington, D. C. The transactions of these annual assemblies and meetings through the ninth were published in the Bulletin series of the National Research Council as follows: Second, 1921, Bulletin No. 17; fourth, 1923, Bulletin No. 41; sixth, 1926, Bulletin No. 53; seventh, 1926, Bulletin No. 56; eighth, 1927, Bulletin No. 61; and ninth, 1929, Bulletin No. 68. Transactions of the tenth and eleventh annual assemblies and meetings held in 1929 and 1930, respectively, were published in June 1930 as one of the miscellaneous publications of the National Research Council. The present Volume,-also one of the miscellaneous publications of the Council, includes the transactions of the twelfth annual assembly. At the first, third, and fifth annual meetings in 1920, 1922, and 1924, respectively, there were no scientific papers presented; therefore, the transactions for these were not printed but were mimeographed for limited distribution only.

The twelfth annual assembly of the Union and the meetings of its sections April 30 and May 1, 1931, were held in the building of the National Academy of Sciences and National Research Council at Washington, D. C.

During the business session of the twelfth general assembly the General Secretary reported on the year's activities of the Union and on the Stockholm meeting and proposed geophysical work in polar regions, and resolutions submitted by the several sections were adopted; following this, there was a "Symposium on Time-Signals" sponsored by the sections of Geodesy and Seismology which emphasized the great need of an extension of existing time-signal service. The individual Section meetings were marked by numerous progress-reports on the geophysical activities not only in the United States but also in Canada and in Mexico. The Section of Geodesy, in addition to such progress-reports, discussed gravity-work, instrumental progress, the moon's influence on latitude, and the establishment astronomically of points on an unsurveyed line. In the Section of Seismology, attention was devoted to theoretical considerations, relations of geodetic operations to seismological interpretations, registration of time-signals, progress-reports on instrumental developments, and the provision made to realize the Union's resolution at its eleventh annual assembly to establish a seismological observatory in South America (near Huancayo, Peru). In the Section of Meteorology much time was given to discussion of the International Polar Year prospects, followed by a report on the Madrid meeting in March 1931 of the International Commission for the Exploration of the Upper Air, discussion of proposed International Cloud Atlas, and papers on atmospheric turbidity, measurement of color of sea and sky, and cyclical variations in relation to long-range weather forecasting. In the Section of Terrestrial Magnetism and Electricity the papers were given in four groups relating to (1) the year's investigations in progress in the United States, (2) the Stockholm assembly, (3) extra-terrestrial considerations, and (4) polar research. The communications to the Section of Oceanography were chiefly progress-reports showing excellent development of oceanographical work in the United States by governmental and private organizations, a discussion of Gulf Stream temperature-investigations and on the measurement of specific gravity of sea-water by the Knudsen

and Plummet methods. In the Section of Volcanology five papers were given relating to the solubility of water in granite magmas, and to the Merapi, Katmai District, Cripple Creek, and Valles Mountain volcanoes. On May 1, 1931, the first annual meeting of the Section of Hydrology was devoted to statements of the formal organization of the Section, the field, scope, and status of the science of hydrology, progress-reports on various governmental and private programs, cooperation of hydrologists, glacier-measurements, hydrologic laboratories, studies in evaporation, and geological relations.

The continued active international cooperation between Canada, Mexico, and the United States was indicated by communications from members of the national committees of our two neighbors reporting on the progress of governmental activities and on results of geophysical researches stimulated by the committees.

On behalf of the Executive Committee of the Union, cordial thanks are tendered the speakers, guests, and members of the Union for their active interest and participation, making possible the success of the meetings, as well as for the promptness with which manuscripts were submitted for publication.

The preparation of the final manuscripts for direct reproduction in this Volume was done by J. J. Capello. The funds for publication have, as in the past, been supplied from the allotment made by the National Research Council for the maintenance of the Union.

J. A. Fleming,

General Secretary

AMERICAN GEOPHYSICAL UNION

Twelfth Annual Meeting

REPORTS AND PAPERS

G E N E R A L A S S E M B L Y

Washington, D. C.
May 1, 1931

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RESOLUTIONS ADOPTED

(I) RESOLUTION ON GRAVITY AT SEA

(Proposed by the sections of Geodesy and Volcanology)

WHEREAS, The United States Navy Department, in cooperation with the Carnegie Institution of Washington, conducted a gravity-campaign in 1928, during which observations were made under the direction of Dr. F. A. Vening-Meinesz, Member of the Dutch Geodetic Commission, at many points in the Caribbean Sea, the Gulf of Mexico, and the Atlantic Ocean to the northward of Porto Rico, thus adding materially to the knowledge of the crust of the Earth in the regions covered, and furnishing data for the figure of the Earth, and

WHEREAS, Much additional information about gravity at sea should be secured to supplement the work already done in the Gulf of Mexico, Caribbean Sea, and West Indian waters, and

WHEREAS, It is only on a submarine that such observations can be made, therefore be it

RESOLVED, That the American Geophysical Union of the National Research Council recommends to the Navy Department that it give thought to the question of continuing its work on gravity at sea and of securing the necessary soundings to supplement such work, especially in the waters of the West Indies including the Caribbean Sea, and be it further

RESOLVED, That a copy of this resolution be forwarded to the Secretary of the United States Navy.

(II) RESOLUTION ON INTERNATIONAL COOPERATION IN THE STUDY OF TIDAL WAVES

(Proposed by the sections of Seismology and Oceanography)

WHEREAS, A communication has been received through the Department of State and the National Research Council from M. Hubert, Secretary of the Commission of the International Union of Geodesy and Geophysics for the Study of Tidal Waves, suggesting and inviting participation of the United States in studying tidal waves and various phenomena associated with them, therefore be it

RESOLVED, That the American Geophysical Union indorses the plan of the Commission and recommends the participation by organizations and individuals of the United States who may be concerned, and in order that a suitable plan for such participation may be developed, the Chairmen of the sections of Seismology and Oceanography are authorized to appoint two members from each Section as a joint committee, and be it further

RESOLVED, That a copy of this resolution be sent to the Secretary of the Commission of the International Union of Geodesy and Geophysics for the Study of Tidal Waves.

(III) RESOLUTION ON COMPARISONS OF NEW TYPES OF SEISMOLOGICAL INSTRUMENTS DEVELOPED IN THE UNITED STATES WITH VARIOUS TYPES DEVELOPED IN EUROPE

(Proposed by the Section of Seismology)

WHEREAS, The Director of the Central Seismological Bureau of Strasbourg, France, has indicated the great desirability of direct comparisons of new types of seismological instruments developed in the United States with various types developed in Europe, and has offered the facilities of the Central Bureau for this purpose, preferably with the cooperation of an American seismologist, therefore be it

RESOLVED, That the American Geophysical Union indorses this plan, and be it further

RESOLVED, That a copy of this resolution be sent to the Director of the Central Seismological Bureau of Strasbourg.

(IV) RESOLUTION COMMEMORATING FIFTIETH ANNIVERSARY OF GENERAL GREELY'S PARTICIPATION IN THE FIRST INTERNATIONAL POLAR YEAR

(Proposed by the Section of Meteorology)

WHEREAS, The American Geophysical Union is lending its influence toward the successful completion of the work of the Jubilee International Polar Year, 1932-33, and

WHEREAS, All the world recognizes in Major-General Adolphus W. Greely, U.S.A., retired, the leader of the Lady Franklin Bay Expedition, 1882-83, of the First International Polar Year, the outstanding figure in Arctic exploration on this continent, therefore be it

RESOLVED, That the American Geophysical Union record its high appreciation of General Greely's abundant contributions to our knowledge and its earnest wishes for the long continuance of his good health, and be it further

RESOLVED, That a copy of this resolution be sent to General Greely.

(V) RESOLUTION ON THE DEATH OF FRANKLIN G. TINGLEY

(Proposed by the Section of Meteorology)

WHEREAS, The members of the American Geophysical Union have learned with profound regret of the death of Franklin G. Tingley, late Chief of the Marine Division of the United States Weather Bureau, therefore be it

RESOLVED, That the American Geophysical Union record its profound regrets over this loss not only to its own personnel but also to the world of science in general, and especially to oceanography and meteorology, and be it further

RESOLVED, That a copy of this resolution be sent to Mr. Tingley's family.

(The joint committee entrusted with the work involved in resolution II consists of Harry Fielding Reid, Chairman, Perry Byerly, H. H. Hook, and H. A. Marmer, the first two named being from the Section of Seismology and the other two from the Section of Oceanography.)

A SHORT REPORT ON THE STOCKHOLM ASSEMBLY AND ON PROPOSED GEOPHYSICAL WORK IN POLAR REGIONS

J. A. Fleming

The Fourth Assembly of the International Union of Geodesy and Geophysics held at Stockholm, Sweden, August 14-23, 1930, was attended by some 302 delegates and guests from 36 countries. Countries not yet adhering to the International Union having representation through invited guests were Austria, China, Esthonia, Germany, Union of Socialistic Soviet Republics, and Venezuela. A total of 27 persons, including 14 official delegates, represented the United States and took a leading part in bringing about the good-will reflected in the attendance of guests from Germany and Austria. The principal activity related to the unanimous adoption of the new Statutes. These Statutes call for the designation of the international sections hereafter as associations and effect a greater decentralization of the Union's own tasks so as to make its associations practically autonomous. The unit of contribution was increased so that the annual contribution from the United States will hereafter be about $3,100. Other important actions included the approval of the proposed Jubilee International Polar Year in 1932-33, an agreement to promote cooperation of the International Research Council and its unions with societies, organizations, or institutions engaged in work extending beyond national lines, and consideration of means to more effectively distribute publications of the International Union and of its associations. The meeting place for the Fifth General Assembly of the Union in 1933 was designated to be Lisbon, Portugal. Dr. Lallemand was reelected President of the Union and Brigadier Winterbotham was elected General Secretary. The following Americans are officers of the international associations: Geodesy, William Bowie, President; Seismology, H. F. Reid, Vice-President; Terrestrial Magnetism and Electricity, J. A. Fleming, President; Oceanography, G. W. Littlehales, Vice-President; Volcanology, H. S. Washington, Vice-President.

The plans for the Jubilee International Polar Year, which had the unanimous indorsement of this Union at its eleventh annual meeting, are well advanced. The first printed report of the International Commission for the Polar Year 1932-33 as designated by the International Meteorological Organization (Premier rapport de la Commission Internationale de l'Année Polaire 1932-1933. Leyde, Secrétariat de l'Organisation Météorologique Internationale, No. 6, iv + 152, 1930) covers the transactions of its meeting held at Leningrad in August 1930 and includes a history of the effort, resolutions adopted for the guidance of the work, and appendices giving in detail reports and recommendations regarding programs of observation in various fields, regarding equipment, and regarding general plans for observatories and quarters. The International Commission for the Polar Year 1932-33 is under the presidency of Dr. D. la Cour, Director of the Danish Meteorological Institute, and includes two American members, Captain N. H. Heck of the United States Coast and Geodetic Survey and J. A. Fleming of the Carnegie Institution of Washington. The program proposed recommends establishing 43 stations in the Arctic and six stations in the Antarctic, the period of observation at each station to be from August 1, 1932 to August 31, 1933. Twenty-six nations have thus far indicated that either their governments or their national academies may participate by organizing special stations or by intensifying programs at their existing stations. Twenty-four of the proposed stations in the Arctic and two in the Antarctic have already been assured. About 55 regular magnetic and electric observatories in other parts of the world will cooperate. The United States has been asked to participate by establishing stations in Alaska near Fairbanks and at Fort Conger and Ellesmere Land. President Hoover, upon the recommendation of the Secretary of State, sent a special message to Congress February 10 recommending favorable consideration of a bill proposing an appropriation of $30,000 for the establishment of a station in Alaska. Although this bill was passed by the Senate and reported unanimously from the House Committee on Foreign Affairs, it failed to pass the House because of the parliamentary rule for unanimous consent in the last days of the session. It is to be introduced again early in the coming session, and it is hoped favorable action may be taken in time to permit establishing the station. Fort Conger may be occupied with cooperation of various interests by a private American expedition.

The Wilkins-Ellsworth Trans-Arctic Submarine Expedition, regarding which Captain Sir Hubert Wilkins addressed the Union at its eleventh annual meeting, was completly organized and is to leave Bergen, Norway, towards the end of June on the submarine Nautilus, provided by the United States Navy and the United States Shipping Board and which has been specially reconstructed for use in the Arctic. The breadth of scientific contact is apparent from those scientific organizations formally extending cooperation to the Expedition--the American Geographical Society, the Carnegie Institution of Washington, the Geophysical Institute of Bergen, Norway, the Woods Hole Oceanographic Institution, and the Cleveland Museum of Natural History. The director of scientific research under Captain Sir Hubert Wilkins is Lincoln Ellsworth whom other plans may prohibit from accompanying the Nautilus. Chief of the scientific staff is Dr. H. U. Sverdrup, one of Norway's outstanding geophysicists who has concentrated on oceanography and terrestrial magnetism. With Dr. Sverdrup will be associated Floyd M. Soule of the staff of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington and B. Villinger of Germany. The geophysical fields promising most fruitful result are those of oceanography and terrestrial magnetism. The Expedition is unusually well equipped with magnetic instruments, Meinesz gravity-apparatus, sonic depth-finder, winch, and complete oceanographic apparatus including water-bottles, reversing-thermometers, chemical apparatus and appurtenances, meteorological apparatus, spectrographic equipment for studying light penetration in the Arctic Sea, etc. Messrs. Sverdrup, Soule, and Villinger will join the Nautilus at Bergen, Norway, where they will complete the installations of apparatus aboard and make tests before beginning the cruise via Spitzbergen, the North Pole, northern Greenland, uncharted region of the Arctic Basin, and Bering Strait. About two months will be required for the cruise as outlined if no unexpected difficulties are encountered.

Dr. H. Eckener has been made President of Aeroarctic to succeed the late Dr. Fridtjof Nansen. Cable advice from the General Secretary of the Society in Berlin states that the short trial Arctic flight of the Graf Zeppelin for the Society is to leave Germany in July. An invitation was received asking that an American geo-

physicist accompany the Expedition which is for the purpose of testing equipment assembled for scientific observations in the Arctic as a trial preliminary to the exploratory flights from Friedrichshafen to Fairbanks and return which are planned for either 1932 or 1933. Lieutenant-Commander Edward H. Smith of the United States Coast Guard has been assigned.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

SYMPOSIUM ON TIME-SIGNALS

(Sponsored by the sections of Geodesy and Seismology)

UNITED STATES NAVAL OBSERVATORY TIME-SERVICE

J. F. Hellweg

I am carrying coal to Cardiff when I address this assembly on the subject of the Time-Service.

Before discussing the Naval Observatory Time-Service, a brief history of the Observatory may be of interest. An amateur astronomer, William Lambert, presented a memorial to Congress in 1809, recommending the establishment of a First Meridian in the United States at the permanent seat of Government. Lambert had previously determined the longitude of Washington and submitted his calculations with his memorial.

Congress procrastinated in settling this very important question. After being repeatedly referred to various committees, commissions, and boards, the Secretary of State, James Monroe, in 1812, took the first positive action in recommending the establishment of an Observatory. After three years of delay, Congress finally acted and then the President failed to act.

John Quincy Adams in his first message to Congress in 1825, urged the establishment of a national university and the erection of an astronomical observatory either as a separate institution or as part of the university.

Ten years later in 1835, the Secretary of the Navy called attention to the great importance of a Naval Observatory to the Government, its effect on the defense of the country, its influence on the Navy, and on the commercial and scientific pursuits of the entire country. Attention was called to the necessity for employing an officer of science to keep maps and charts, to regulate chronometers, and to preserve all mathematical and philosophical instruments required for the Naval Service. Again no action was taken.

Three years later, in 1838, John Quincy Adams entreated President Van Buren to use the income from the Smithsonian bequest in establishing an astronomical observatory and to pay the salary of one astronomer and one assistant, for nightly observations, for the periodical publications, and for annual courses of lectures upon natural, moral, and political sciences. Four years later, in 1842, John Quincy Adams again urged the establishment of a national observatory. In Adams' memoirs it is stated that the powerful opposition to the establishment of an astronomical observatory during this long period was due in a large measure to the political enmity towards Adams. In spite of all this determined opposition, the establishment was effected in an entirely different way, a way not contemplated by either the advocates or the opponents of such an institution.

Until 1830 each vessel of the Navy when fitting out obtained its instruments and charts by requisition on the Board of Naval Commissioners, the purchases being made by a Navy agent from foreign governments or from private dealers. No tests were made of either instruments or charts prior to their purchase. When a ship was decommissioned her instruments and charts were piled in a store-house where they were neglected until another ship was commissioned and needed them. Then they frequently were found unfit for use.

In 1830 Lieutenant Goldsborough made a definite recommendation that a suitable place be designated for the proper stowage of all chronometers, instruments of precision, theodolites, circles, telescopes, charts, etc., and that a competent officer be made personally responsible for all instruments placed in his charge. Based on Lieutenant Goldsborough s recommendations, the Secretary of the Navy in 1830 ordered a depot of charts and instruments to be established in Washington, D. C.

Among the functions of this depot was the ascertaining of errors and rates of chronometers. This was accomplished by means of sextant- and circle observations.

These instruments were mounted in a circular building near a house on what is now G Street between 17th and 18th streets, Northwest.

At the time of the establishment of the depot, charts and books were purchased abroad and frequently were in foreign languages. The Naval commissioners ordered Goldsborough, upon the latter's recommendation, to make modifications in charts, to reduce them all to the meridian of Greenwich and to translate all notations into English. Goldsborough was relieved by Lieutenant Wilkes who, in 1834, evidently tired of the procrastination of everyone and built the first observatory-building at his own personal expense. He mounted in it a transit made by Troughton in England for the Coast Survey in 1815.

From such a meager beginning the present Observatory grew. After thirty-three years delay, in 1842, the Secretary was finally authorized to contract for the building of a suitable house for depot of charts and instruments. Lieutenant Gillies prepared the plans after going abroad and consulting distinguished astronomers.

In 1844, Lieutenant Maury, who relieved Wilkes, was ordered to take charge of the new quarters and to move all instruments, charts, etc., into the new building.

Wilkes was at heart an astronomer; Maury was more inclined to develop the hydrographic and meteorological work. While considerable work had been done by Wilkes in the field of hydrography and also by other officers, it was Maury who really laid the foundations of the extensive system for hydrographic work of the Navy Department. He organized the system for the collection of information from the logs of all ships both naval and merchant. He collected information of ocean-currents, wind, pressures, temperatures, water-temperatures, and other marine and meteorological phenomena from all over the world from which he made his charts. The system still continues and, on it, is based the present really marvelous work of the Naval Hydrographic Office, whose publications are now so eagerly sought by the mariners of all nationalities.

It was not until one year later, 1845, that observations of the Sun, Moon, planets, and brighter stars were begun systematically, and have been continued since. The results of the first year's observations were published in 1846 and the publication was called "The first volume of astronomical observations ever issued from an institution properly entitled to the name of an observatory on this side of the Atlantic."

The following year the Secretary of the Navy directed the Superintendent of the Depot of Charts and Instruments as follows: "The country expects also that the Observatory will make adequate contributions to astronomical science." The Naval Observatory, by its geographical position, was directed to inaugurate observations of the heavens, commencing at the lowest parallel of south declination possible and to embrace in its catalog all stars, even of the smallest magnitude which the instruments could accurately observe.

This was the first definite program of observations outlined for the Naval Observatory. Since March 21, 1846, when the work was begun on the first catalog of stars, definite programs have been followed continuously. Some of the old instruments used in the first cataloging of stars are now in the Museum where they excite considerable interest.

The Naval Observatory gained considerable prominence among the world's astronomers in 1847, through the discovery by one of the staff that the planet Neptune, which had been discovered on September 3, 1846, was identical with the star seen twice by Lalande in May 1795, and which he had listed in his star-catalog. The researches which resulted from the Observatory's discovery afforded the means of accurately determining the orbit of Neptune. Between 1854 and 1860 three minor planets were discovered by the Observatory.

In 1870, Congress authorized the construction of the largest size refracting-telescope of American manufacture. A subsequent act provided for the housing of this telescope.

Alvan Clark of Cambridgeport, Massachusetts, constructed a refracting-telescope with a clear aperture of 26 , mounted equatorially on the German plan, with all the usual counterpoises and other easy motion-devices, driving-clock, etc. This telescope was mounted in 1873 and we are still using that instrument.

The excellence of the Naval Observatory's work was soon recognized by the world's most famous astronomers, and the United States was invited to send representatives to all international conferences.

In 1842 Captain Wilkes was the first to use the telegraph for ascertaining differences of longitude. His first attempt was between Baltimore and Washington. In 1868 and 1869, with the aid of the Western Union Telegraph Company, the Naval Observatory undertook the determination of longitude by means of telegraph, between the stations in Havana and several continental stations in the United States.

In 1912 the Naval Observatory suggested to the International Conference held in Paris the determination of the difference of longitude between the observatories in Washington and in Paris by means of radio time-signals. This work was done in 1913 and 1914, the Naval Radio Station at Arlington and the station at Eiffel Tower in Paris being used for these communications. These observations were the first direct determination of the difference of longitude and also the velocity of the transmission of radio waves between the United States and Europe.

The Naval Observatory has participated in the observation of all eclipses and has been the backbone of these eclipse-expeditions. An example is the last eclipse at Niuafou, where the Navy Department bore all the expense and invited representatives from various observatories to become members of the party. As a matter of fact, we not only handled our own Naval Eclipse-Expedition but even handled the Australian Expedition, furnishing them with quarters, subsisting them, and aiding them in mounting their instruments--and then, to top it off, we saved them three weeks of delay by sending them on one of our naval mine-sweepers to a distant island where they could catch a steamer for Australia. It later developed that had this courtesy not been extended, the weather-conditions were such that they might have been stormbound on the island of Niuafou for a very long period.

The Naval Observatory is a national institution. By the time it was transferred to its present location it had become recognized as one of the highest ranking observatories in the world due to the character of its work in astronomical research.

The Naval Observatory has a dual personality. It serves the naval services and merchant-marine service in many ways with which you are more or less familiar. It also serves the general public throughout the country in equally important ways. It is the only governmental institution of this kind to render such service. Its primary mission is the determination of absolute position by astronomical observations and the maintenance of a continuous series of observations of the Sun, Moon, planets, and the standard stars of the American Ephemeris, in order to prepare all the necessary tables for the Ephemeris. It also maintains a series of stars which may be necessary to serve future possible needs. In addition to its astronomical character, the Observatory also acts as the Materiel Desk of the Bureau of Navigation of the Navy Department and handles the procurement and upkeep of all instruments used in the naval service for navigation.

The service rendered to the country at large, and which most intimately affects the lives of all of our citizens, is our Naval Time-Service.

Few people in our country realize how far-reaching is the influence of our time-service. A few years ago the Western Union Telegraph Company decided to reduce the length of the broadcast from five minutes to three minutes. In other words, to begin at 11:57 instead of 11:55. The number of protests that were received indicated that the average citizen considered that he was being robbed of one of his inalienable rights. Many amusing stories are told of the daily gatherings of cowboys, engineers, prospectors, race-track touts, etc., at little local telegraph stations all over the country, each with his watch in hand waiting for that noon-tick, and the Lord help any fellow who happened to talk too loud between 11:55 and 12 o clock. These groups hung on that event with bated breath and then immediately after the zero-hour there was a babble of voices, rowing over whose watch kept the best time.

As you all know, the duty of keeping the nation's time is a very important one and a very technical one. Every nation in the world maintains a costly time-service, for the determination of the time is very expensive--expensive instruments for observing the stars, chronographs for recording the exact instant when the celestial bodies cross the meridian, precision-clocks for maintaining the time as accurately as it is humanly possible to maintain it. Then, in addition, there is the cost of labor, including the astronomers who nightly observe the stars as they cross the meridian of the Observatory; the highly technical computers who make the calculations based on these observations; the electricians who handle the many electrical details of time-keeping; the radio experts who broadcast daily the exact time to the hundredth of a second; and the telegraph personnel who signal the time to all parts of the continental limits of our country by land wires. All of these total a sum for keeping the nation's time which mounts very rapidly and yet nobody regrets it. It is well worth it, for without correct time many of the smooth-running activities of this country could not have been developed.

Have you ever thought of the many times a day somebody asks the question "What time is it?" or, "Will you please give me the correct time?" Ask the Western Union Telegraph Company why they had to stop answering this question. Thousands and thousands of telephone calls daily all over the country were pouring in on the Telegraph Company's offices until the interference with their business was so serious that they reluctantly had to refuse to answer the question. For the same reason the Naval Observatory had to stop answering the question.

The many activities which depend on our time-signal are too numerous to enumerate here. Of course you all know that gravity-investigations are dependent upon our time; that navigators of ships depend on our time-signals for safe navigation of their vessels; that all boundary commissions are dependent upon the accuracy of our time-signals that geologists and mineralogists use our time-signals in their work; that the wonderful train-service in this country would be impossible without exact time. In fact, there is hardly any activity in our country that is not either directly or indirectly affected by the question of correct time, and to determine this time accurately we are dependent upon the stars.

As you all know, the real Sun is variable in the time that he passes the meridian. As a result, for keeping time we have had to invent a mean sun--a fictitious sun--whose daily movements are absolutely uniform. But no such subterfuge is necessary with the stars.

As the Earth rotates, the stars in the heavens appear in the east and after swinging across the heavens set in the west. The only difference between the stars' behavior and the Sun's behavior is that the stars make the round trip in almost the true period of the Earth's rotation, while in the case of the Sun a little more than a revolution is necessary to bring the Sun back again to the same meridian. As the stars are not within the Earth's orbit--in fact they are so far distant that their apparent positions are only very slightly effected by the Earth's motion--the period of the Earth's rotation measured in reference to the point of the sky called the vernal equinox equals one sidereal day. This period is the most accurate standard of time measured. The Earth's rate of rotation is constant and the stars move very slightly with reference to the vernal equinox, so that they are very reliable as reference points to measure the time of the Earth's rotation.

Here at the Observatory we use transit-instruments for observing the transit of the various stars. These instruments, as you all know, are used to mark the exact instant when the star passes across the celestial meridian. The sidereal time at which each star will cross the meridian is calculated. For greater accuracy, we select the stars which cross the meridian near the zenith of Washington, and also those stars whose exact positions are most closely known.

The exact time, according to the clock, that the stars cross the meridian is recorded by a chronograph. The difference between the time the stars should cross the meridian and the time that they are found to cross the meridian according to our clocks represents the error of our clocks. These errors are very accurately determined.

Down in a vault at the mathematical center of the Observatory estate are three sidereal clocks. I will not describe the present vault, but rather the new vault which we hope to have completed within the year, as it embodies all the latest gadgets to assist us in timekeeping.

Our new vault will be made of hollow tile. It will be surrounded by an air-space of about two and one-half feet, outside of which space will be built a reinforced-concrete vault. This air-space will entirely surround the inner vault. The entire structure will be below the frost-line, the roof of the outer vault just touching the frost-line. The walls of the outer vault will be continued above ground and the space enclosed will be arranged into an office where all the records of timekeeping, etc., will be kept. The inner surface of the inner vault will be white enamel and on each wall, let in from the surrounding air-space, will be two lights very similar in arrangement to the magazine-lights on board our battleships. These lights will be capable of overhaul and adjustment without entrance into the inner vault. Every light will be projected by reflectors into the vault, brilliantly illuminating the whole space. There will be six separate piers, each one in a different plane, so that when the sidereal clocks are mounted on the piers no two pendulums will swing in the same plane. Air-pressure and air-temperature will be automatically kept constant. We are going to install quite an innovation in our new clock-vault in order to satisfy the ever-present demand of visitors to see the wonderful clocks that keep the nation's time. Let down through the center of the roof of both the outer and the inner vault will be a periscope so that the astronomers and the visitors in the upper office can look into the vault and actually see the clocks running, even better than if they were in the vault itself, as they will get a perspective of the whole thing.

At present we have three Riefler clocks which were bought about 30 years ago and which, at that time, were the most accurate timekeepers that could be obtained. We have recently obtained a new Shortt clock, and this year expect to obtain our second. Next year we will obtain our third and then we will have six clocks operating in our vault.

These clocks are never reset or interfered with in any way except in the case of necessary repairs. The actual rate of each clock is determined by checking it with the meridian-passage of the stars, and then by applying these corrections to the face-time of the sidereal clocks we know the exact sidereal time. Rate-curves for each clock are continuously maintained.

Up in the time-service room are two transmitting-clocks which keep 75th meridian mean time and which are really the clocks that broadcast the time-signal.

The standard-time of the United States is called the "standard mean solar time." As stated above, due to the Earth's variable motion in its orbit and the inclination of the Earth's axis, apparent solar days vary in length during the year. For obvious practical reasons, it is necessary that all days and all hours be of exactly the same length. Therefore, the mean solar time has been established and the difference from the apparent time is the equation of time which is calculated and recorded. By applying the equation of time you can convert apparent time to mean time and mean time to apparent time. The value of this equation of time is one of the functions which is published for every day of the year in our Ephemeris and Nautical Almanac.

In order to reduce confusion and to standardize timekeeping in this country, standard time-zones have been created. All the points in each zone use one uniform time. These zones are on even hours and are measured from Greenwich, which is the zero-meridian of the world. In continental United States there are four time-zones: The Eastern Standard-Time, or the local time of the 75th meridian which is exactly five hours behind the Greenwich standard-time; Central Standard-Time is the next zone and is the local time of the 90th meridian which is exactly six hours behind Greenwich time; Mountain Standard-Time is the third time-zone and is the local time for the 105th meridian which is exactly seven hours behind the Greenwich time; and the last time-zone in the United States is the Pacific Standard-Time which is the local time of the 120th meridian which is exactly eight hours behind Greenwich time.

The Naval Observatory is thus able to broadcast one time-signal which will pro-

vide time for all of the zones. Our time-signals are broadcast three times daily, at 3:00 a.m., at noon, and at 10:00 p.m.

These time-signals are broadcast automatically by means of our transmitting-clocks. We have two transmitting-clocks in the time-service office which are controlled electrically so that they can be set within one-hundredth of a second. They have an electrical break-circuit apparatus for emitting the signal automatically. About ten minutes before each broadcast is made, these transmitting-clocks are compared with our standard sidereal clocks in the vault by means of a chronograph. A magnet and a solenoid in the middle of the swing of the pendulum permit the operator to either speed up or retard the swing of the pendulum, thereby permitting him to set the clock exactly on time. It usually takes five or six minutes to make the necessary comparisons and set the clocks on 75th meridian time.

From 2:55 a.m. until 3:00 a.m., from 11:55 a.m. until noon, and from 9:55 p.m. until 10:00 p.m., Eastern Standard-Time, the ticks of one transmitting-clock are broadcast by both Arlington and Annapolis on many different frequencies so as to make it possible for everybody to obtain the time-service.

The beat of each second is transmitted except the 29th second of each minute. Therefore, after having counted 28 beats, the 29th, remaining silent, acts as a finger pointing to the next second announcing to the world that the next second will be 30th second of a minute. In order that anyone tuning in on the broadcast during the five-minute interval can know exactly what minute he is listening to, a system of identification signals has been prepared. If the 51st tick is omitted, it indicates that there are four more minutes to go. If the 52nd second is omitted, there are three minutes to go. If the 53rd second is omitted, there are two minutes to go, and if the 54th second is omitted, there is only one minute to go. From the 55th minute up to and including the 58th minute, there are no ticks transmitted for the 56th, 57th, 58th, and 59th second, so that anyone listening will know that after a silence of four beats, the next beat is the 60th second, or the beginning of a minute. On the 59th minute there are no beats transmitted from the 50th second until the 60th second, so that if you note no beats transmitted for 10 seconds, you know that the next beat will be the zero-hour, either 3:00 a.m., noon time, or 10:00 p.m.

At five minutes before the zero-hour, when the operator throws the switch which automatically makes the transmitting-clock control both of our powerful broadcasting stations, Arlington and Annapolis, it also throws into circuit our own receiving-set so that we receive in the same room, the time-signals which can be heard all over the world. We have a very ingenious recording-device which was invented by Mr. Sollenberger, who has charge of the Time-Service, which shows on one record the ticks of the sidereal clock, the ticks of the transmitting-clock which broadcasts the signal, the radio tick from Arlinrton, and the radio tick from Annapolis. This record not only shows comparison between all of these important records, but also records the exact length of each signal sent, and by means of a micrometer-arrangement the coincidence can be measured to a hundredth of a second visually.

Immediately after the zero-hour and after the operator has thrown out all the switches, this record is checked and the lag between the clock-time and the broadcast-time is measured. Each week we send a correction-sheet to all activities which require exceptional accuracy in the time-service, so that they can check back and obtain the exact time for any broadcast of any day.

Some time ago a newspaper feature-writer wrote a very glowing account of the wonderful time-service broadcast by a foreign government. In this article there were a number of inaccuracies. Among others, it was stated that the Washington local time was not very important, but that when the Naval Observatory relayed the time-signal it was announcing to the world that it was ten o'clock at Greenwich. As a matter of fact, we have never broadcast at that time nor have we ever relayed any other observatory's time. I felt this thing so keenly that I requested the newspaper to correct the inaccuracies which they had published. In order to insure that my statements were absolutely correct, I checked them with the official reports of the foreign observatory, and I was very much surprised to learn that the United States Naval Time-Service broadcast its first time-signal nineteen years before any other government. The Navy began in September 1903, installing equipment at Navesink, New Jersey, at

our Naval Radio Station there. In the early spring of 1904, the Navy began broadcasting time-signals at low power. Our closest competitor, Great Britain, broadcast its first radio on low power via British Broadcasting Company on February 5, 1923, just 19 years later.

In December 1912, when our Arlington high-power broadcasting station was completed, we immediately began broadcasting our time-signals on high power, which permitted our time to be heard practically all around the world. The Rugby time-signal, which is the British high-power service, was not placed in effect until December 19, 1927, just 15 years after we began our high-power broadcast.

From this you see that the Naval Observatory does not and never has acted as a relay to any other observatory. We obtain our own time by astronomical observations and we broadcast it at the times decided upon as best suited for American purposes.

I have digressed to make this statement in order that if any of you read the article you may know the facts--that the United States was the first to begin time-signals by radio broadcast, and that we have always kept in the lead. We have never been a follower.

From time to time efforts have been made to have the Naval Observatory increase the number of broadcasts. In March 1913, we began broadcasting the 10:00 p.m. signal and on April 5, 1928, in response to the many requests from the far Pacific, we began our 3:00 a.m. broadcast, as the reception at that time was far superior for those in the far distant Pacific.

I have been informed that it is the desire of some activities in the United States to have an hourly broadcast. Unfortunately, that is impossible both because of the enormous expense and because of the still more serious interference with other equally and in some instances more important government business. Since learning that additional broadcasts are desirable, I have investigated the condition of the broadcast-program and I have been astounded at the number of hours of broadcast and the practical impossibility of finding a little hole any place in the day's program where we could squeeze in additional time-broadcasts.

There is another phase to this situation which warrants consideration. If we broadcast every hour on the hour, like the Pennsylvania Railroad system, it may be very convenient for some few, but it will enormously interfere with many others who are also on the air seeking information. After the few who want the hourly broadcast have completed their immediate work, the broadcast will go on and on indefinitely, eating up government funds and without a proper return for the expenditure. It will be very much like the case of the London newspaper reporter who one day noted that there was a Royal Marine pacing up and down on a path in Hyde Park. The reporter, with the usual inquisitiveness of a reporter, asked the Marine what he was doing there. The Marine stated that it was his orders to patrol that post, but he did not know why. The reporter's curiosity was fanned to fever heat and he went to the Admiralty to learn why the Royal Marine was marching up and down in Hyde Park. Nobody knew why, and then they all began to dig through the records to find out why a Royal Marine was on duty in Hyde Park. It developed that some hundred years before, a British Admiral lived in a house facing on Hyde Park and the old Admiral was in the habit of walking out in the Park every morning after breakfast for a short constitutional. He had a park bench placed on the walk facing his house where he could rest after his walk. One day, when the Admiral sat on the bench he was horrified to feel the softness and wetness of nice green paint. He rose up from the bench in a fury and damned everything in sight like a good old sailor. He immediately went to the Admiralty and demanded that they put a sentry on that bench to keep those damned land-lubbers from painting that bench and spoiling his uniform when he sat down. The dear old Admiral has long been dead and his house has been torn down, but the Royal Marine was still marching post over an invisible green bench a hundred years later. This is a darned good story, and it may or may not be literally true. I have told it as it was told to me, but it illustrates my point. I don't want the Naval Observatory to be walking post for 110 years on the time-service, because some few wanted the time-service at a particular time.

I have a better scheme to offer. If these activities that want special time-signals will formulate their own requirements, crystallize their own ideas of exactly

what they want, what locality they want it in, what frequency they will require for the broadcast, and for how long they will need the broadcast, the Observatory will then be able to meet their demands unless they are excessive. I feel sure that we can come to some middle ground and that we will be able to furnish special time-broadcasts for limited periods which will amply cover the demands of special activities, for definite periods of time. This is much better. It will give those desiring it a special time-signal exactly when they want it, and as soon as the necessity for that time-signal service has elapsed, the government will be saved the expense of further and needless marching up and down to keep some fellow from painting that bench green.

U. S. Naval Observatory,
Washington, D. C.

Discussion

N. H. Heck (United States Coast and Geodetic Survey)--Supplementing communications from a number of leading seismologists which, however, are not in sufficient detail to give the reason back of their recommendation, it should be understood that modern seismology has a very definite and direct relation to the time-signals of the Naval Observatory. Every record contains a number of such signals, in many cases recorded automatically, and each record would be improved by more frequent time-signals.

With particular reference to the recording of near earthquakes which is being done in California and in the Mississippi Valley, I have recently talked with those most concerned, whose communications have been read. Dr. Gutenberg assures me that he is in many cases locating earthquakes to within two kilometers, when his records are good, time is accurate, and there are four recording stations surrounding the epicenter. Since velocities used for this purpose may be eight kilometers per second, obviously accuracy of less than within 0.1 second of time is insufficient. Drums cannot be kept revolving with accuracy over periods of considerable length so time-signals each hour would help greatly in securing the required accuracy.

The necessity for locating epicenters to this degree of accuracy lies in the purpose of the work--to definitely associate earthquakes with geological formations. It is foolish to talk of earthquake-prediction at the present time, but if it ever becomes possible it will be only through such accurate observations carried on until the history of events leading up to strong earthquakes has been ascertained. Seismology is growing and the demand for time-service at more frequent intervals to meet its needs will continue to grow.

There is also need for these signals in teleseismic work. Many different organizations are operating seismological stations throughout the country and especially along the Atlantic seaboard. The stations are especially well arranged to record waves at successive distances from the epicenter in the case of Central American earthquakes but results are of value only with well-coordinated records through absolute time placed on them at frequent intervals.

The proposed program for strong-motion instruments in California which has been described to the Section of Seismology also requires reasonably correct time though the present service would be adequate for this purpose.

It is my opinion that hourly signals would be of adequate frequency. I would like Captain Hellweg to state whether there would be any advantages in having any signals that might be added cover a shorter period than three minutes.

J. F. Hellweg (United States Naval Observatory)--It will probably make little difference. We have to clear the air and also have our astronomer stand by. His necessary work will be the same regardless of length of signal. The only advantage would be a slightly shorter interference with broadcasts which might be worth considering. If you once get the system running it does not make the slightest difference. Of course, a one- or two-minute broadcast would interfere less than the five-minute broadcast. The Western Union shifted their broadcast to three minutes from five minutes. However, the thing is this. The Observatory is very proud of the service and we do not want any criticism against it. If it is humanly possible to

increase the number of time-signals I am willing to do it. There are two holes in the whole service and only two. I do not know what times they are. Everybody would have to accept the same frequency. If everybody who wants it would concentrate on one frequency we could send it out on one frequency. We will meet you fifty-fifty.

It would be ideal for you to have this service but you have not considered how much it would cost to give it to you. Think of the thousands of people all over the world who are listening in and want to get other information. They have to transmit on a number of different wave-lengths. If you can give us a period during which you require a certain signal and the localities and the power to use, we may arrange to give you the signal-service you want. It might be possible to give you one at five o'clock in the afternoon.

May I add one other thing. The Australian Commission wrote to the Observatory and asked us to run a special signal for them. We also got a special request from the Canadian Survey. We received very nice letters from these thanking us for our work.

Paul Sollenberger (United States Naval Observatory)--In order to make frequent time-signal service available to everybody it would be necessary to broadcast the signals simultaneously on several different frequencies. On account of their skip-distances, no one of the short wave-lengths can serve everybody. It would be a comparatively simple matter for the Naval Observatory to transmit time continuously, but difficulty arises because of the necessity of utilizing the services of the radio transmitting-stations on several frequencies.

It occurs to me that a possible solution of the question for the seismologists is the use of more exactly synchronized alternating-current. At the present time we have power-companies all over the country which are more or less synchronized with Naval Observatory time. While I have not investigated the matter sufficiently to speak with certainty, it seems likely that by the introduction of suitable equipment the power in Washington could be made correct within a small fraction of a second. If methods could then be developed for extending this synchronization throughout the country, it would then be possible for anyone to whom electric power was available to have continuous time-service.

TIME-SIGNALS FOR ELECTRICAL AND PHYSICAL MEASUREMENTS

Frank Wenner

In different problems in physical and electrical measurements, one of the most serious problems is that of securing reliable and frequent time-signals. While the rates of good clocks and chronometers can be determined from the Arlington signals as supplied by the Naval Observatory to the required accuracy, the second or half-second signals obtained from them are not sufficiently reliable and in some cases not of sufficient frequency to meet the needs. For some of these problems, what is needed is 20 and preferably 100 or 1,000 signals per second uniformly spaced over each second to a 0.0001 second or better, and uniform over periods of an hour or more to a part in a million or better. Second-to-second tests of the signals obtained from the Bureau of Standards Riefler clock through the contact supplied with it and relays show a dispersion of 0.01 second and more, so it would not meet the requirements even if the signals were of sufficient frequency. Figure 1 shows a record of the signals from the Riefler clock as well as from a chronometer. The missing signals are at the 59th seconds of alternate minutes. The more uniform signals are from the chronometer, and these serve to show that the scattering of the signals from the Riefler clock are not to be attributed to the recording-mechanism.

Fortunately most of the Bureau of Standards' needs are now fully met by the cyclic electromotive forces supplied by a master piezo-electric oscillator. These are of various frequencies, but each is a simple multiple or sub-multiple of the fundamental which is 100,000 cycles per second. Other needs are fairly well met by a light-beam reflected from a mirror attached to the pendulum of a synchronome-clock. Over short intervals of time no irregularity in the signals from the piezo-electric

oscillator have been observed, and hour-to-hour tests indicate variations in the rate of only a few parts in 10,000,000. Even these small observed variations may not be real. It is possible that they result mainly from the variations in the rate of the Riefler clock and the uncertainties in the comparison because of the irregularities in the time-signals received from it.

The difficulties in getting reliable and frequent time-signals constitute a problem with which I had been concerned during a number of years previous to the perfection of the piezo-electric oscillators and previous to the installation of a synchronome-clock. During that time studies were made of various devices for obtaining directly and over wire-lines definite time-signals from clocks, chronometers, and tuning-forks. Probably a description of several of these devices would be of interest, but the time at my disposal will permit of reference but to one. This is a contact applied to the lower end of a pendulum in such a way as to have but slight effect upon its rate and which operates in the grid-circuit of a vacuum-tube. While only a rough model of this type of contact has been constructed and operated only a few million times, we have every reason to think it can be made to operate over short intervals of time to well within a 0.0001 second, and over periods of an hour or more to the full precision of the clock. Since no relay is used, there is no loss in the precision of the signals in putting them on a wire-line and would be none in putting them on a wireless transmitter. Incidentally the duration of the signal is controlled mainly by constants of the electrical circuit so it may be varied over wide limits, possibly from a 0.001 second or less to a 0.1 second or more. In this model the part of the contact attached to the pendulum consisted of a piece of a safety-razor blade. The part of the contact attached to a fixed support consisted of a tungsten wire of from 0.008 to 0.012 mm in diameter and about 2 mm in length. The parts of the contact are adjusted so that the edge of the razor-blade just touches the end of the tungsten-wire when the pendulum is at the center of its swing. The performance was satisfactory when adjusted so that the energy absorbed per contact was equal to the force of one milligram acting through a distance of one mm.

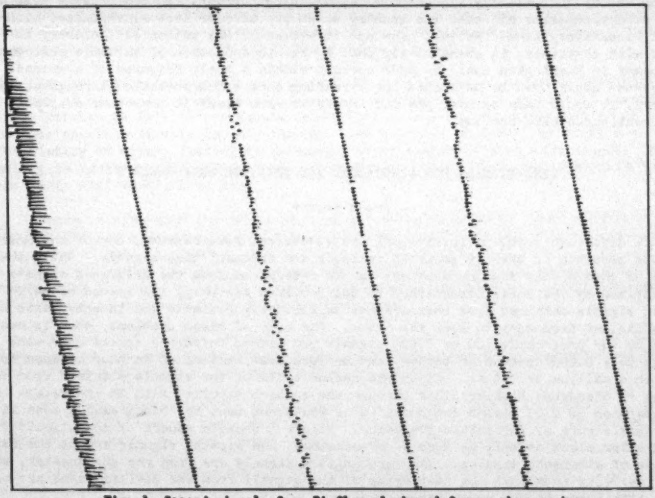

Fig. 1--Second signals from Riefler clock and from a chronometer

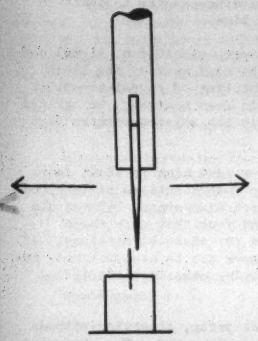

Fig. 2--Electrical contact at lower end of clock-pendulum

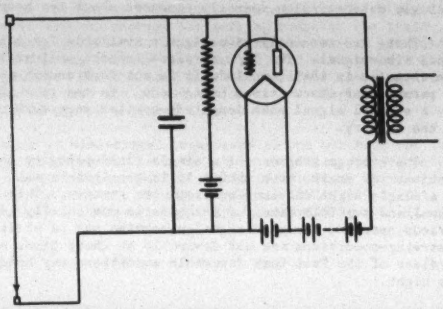

Fig. 3--Circuit-arrangement for putting the signals over a wire-line without moving mechanical parts

Figure 2 shows the parts of the contact. When the razor-blade passes over the tungsten-wire the latter is set in vibration but in air this vibration ceases in less than one-fourth of a second. Whether or not a special damping-device would be required if the pendulum were placed in a vacuum is not known. Figure 3 shows the contact connected to the vacuum-tube and an arrangement for getting the signal on a wire-line without moving mechanical parts.

U. S. Bureau of Standards,
Washington, D. C.

Discussion

Paul R. Heyl (United States Bureau of Standards)--I think Dr. Wenner has done well to emphasize the necessity of avoiding the use of relays in the transmission of signals. In the gravity-work at the Bureau of Standards we are transmitting our signals from the master-clock without relays. In this case we are drawing the signals from the master-pendulum photo-electrically. We prefer that to any form of mechanical interference. The relay is something that must be avoided in all precision-work.

TIME-SIGNAL NEEDS FOR GEODETIC WORK

Edwin J. Brown

Radio time-signals are used by the Coast and Geodetic Survey in carrying on the field-operations in (1) longitude-determination, (2) gravity-determination, and (3) azimuth-measurement. A brief description will be given of the present methods employed on these phases of the geodetic operations and the advantages which would be realized from more frequent signal-broadcasts will be stated.

Longitude-determination--Under present methods the observations required in determining the value of longitude are as follows: (1) Observation of a time set of six stars; (2) chronographic recording of a radio time-signal; (3) observation of a second time-set of six stars. Two time-sets are necessary in order that the rate as well as the correction to the field-timepiece (a break-circuit chronometer) may be known. As the chronometer cannot be depended upon to maintain a uniform rate over periods greater than one hour, it is essential that the mean epoch of either time-set be not more than one hour removed from the time of signal-reception.

The observations outlined above constitute one independent determination of longitude. Two such determinations, agreeing within certain specified limits, are required

to complete the observations on a field-station. The observing-program incident to a single determination normally consumes about two hours' time.

There are two daily time-signals available for this work--the 10 p.m. signal and the 3 a.m. signal. The 10 p.m. signal cannot ordinarily be used west of the 115th meridian, as in that longitude it is not dark enough at the time of signal-reception to permit star-observations being made. In the past it has been necessary to arrange for a special signal when longitude-parties were working in the extreme western part of the country.

The average progress of a single field-party at the present time is about four stations per month, even though it is possible to make two determinations of longitude in a single night and thus complete the station. This great discrepancy between the actual and possible rates of progress is due chiefly to the fact that only those periods near the times of signal-reception may be utilized for star-observations. If observing-conditions are not favorable at these times no work can be accomplished, regardless of the fact that favorable conditions may hold during other periods during the night.

Were hourly signals available for use of the longitude-party, observing-methods could be greatly modified and a much higher rate of progress expected. The observing-program for a single determination could consist of a single star set and two consecutive time-signals, the chronometer-rate being determined from the time-signals and not from the star-sets. Three consecutive time-signals with two intervening star-sets would give two independent determinations and enable the observing-party to complete the work on a station in the same length of time now required for a single determination. Also, since a continuous check on the chronometer-rate could be had from the time-signals, observation of a single star-set could, when necessary, be extended over a period of several hours. With hourly time-signals available, the progress of a field-longitude party would be increased by at least two stations per month. This would result in a saving of about $4,000 on the longitude-work ordinarily executed each year.

Gravity-determination--In determining the intensity of gravity, the Coast and Geodetic Survey uses the relative method. With this method a pendulum of invariable length is swung first at some station where the value of gravity is already known and then at a new station, the period of the pendulum being determined at both stations by comparison with the radio time-signals. The difference in the value of the pendulum-periods for the two stations is a measure of the difference in the intensity of gravity of the stations.

In the past the pendulums were swung for at least two days at each station, and under this method two daily time-signals were sufficient for the proper execution of the work. At present, however, apparatus and methods are being developed with which it is believed it will be possible to determine the value of gravity in a 5-hour period. There are no 5-hour signal intervals available, except that between 10 p.m. and 3 a.m. signals, and as this is not a convenient time to make the observations, most of the work must be accomplished between the noon and 10 p.m. signals. This necessarily limits the maximum speed of operation to one station per day and even this rate of progress cannot be realized, as the field-party cannot always be ready to function at a specified time, and, too, there will be a certain number of failures to record time-signals. On this new work hourly signals are extremely desirable and would result in nearly doubling the rate of progress of the field-parties. The value of such increased progress would probably amount to about $5,000 yearly.

Azimuth-measurement--Astronomical azimuths are measured by means of observations on some close circumpolar-star, usually Polaris. It is necessary that an accurate timepiece, usually a ship's chronometer, be available to time the pointings on the star and, of course, the chronometer-rate and correction must be determined. While radio time-signals have been used to some extent as a means of determining chronometer-corrections for this work, these corrections are usually determined by star-observations. The reason for not using the time-signals to any great extent can be chiefly attributed to the fact that the signal-broadcasts are too infrequent to permit the field-party to use them with any degree of convenience.

If the signals were broadcasted frequently enough to permit their universal use on this type of work there would be, no doubt, some time saved on field-operations. However, the time saved would serve more to shorten the working hours of the field-party rather than to accelerate party-progress. There would be some saving effected by eliminating the necessity of computing the star-sights, but this saving would not amount to more than about $500 yearly. For the most part the benefits accruing from the use of time-signals in connection with the azimuth-observations are largely intangible and no exact monetary value can be assigned to them.

Summary--Increasing the number of time-signal broadcasts to one per hour for the greater part of the day and night would result in a saving to the Coast and Geodetic Survey, on geodetic operations alone, of about $9,000 or $10,000 yearly. This is a conservative figure and in no way includes the intangible value which would result from making possible the accomplishment of more work in any given time by a limited personnel.

U. S. Coast and Geodetic Survey,
Washington, D. C.

LETTERS BEARING ON SYMPOSIUM

(Read by H. E. McComb, Secretary)

James B. Macelwane, S.J., Director, Department of Geophysics, Saint Louis University, Saint Louis, Missouri (April 14, 1931)--I regret very much that my illness and a comparatively slow recovery with the consequent interruption of classes has made it impossible for me to prepare a paper or to get away from the University for the meeting of the Union. I should have liked very much to be present and to take part in the discussion, particularly of the project of more frequent broadcasting of time-signals for seismographic records. The difficulties in the way of reception and the comparatively large cost might prove insuperable obstacles to routine broadcasting of minute-to-minute signals. If the difficulties could be overcome minute-to-minute signals would be the ideal. It would be a great step forward if we could have hourly time-signals of precise character. Cost of these would not be so great and it would permit the placing of a sufficient number of precise time-marks on each record to permit the construction of a comparatively exact correction-curve and would synchronize rather effectively all the records over the country.

Harry O. Wood, Research Associate, Carnegie Institution of Washington, Seismological Laboratory, Pasadena, California (March 11, 1931)--In my judgment it is urgently desirable that time-signals be broadcast at more frequent intervals than is the present practice, and especially that such broadcasting be carried out on the Pacific Coast as well as in the east and the central part of the country, so that the signals may be received clearly in the west. From the seismological point of view it would be ideal if a signal could be broadcasted every minute, or at some similar short interval, so as to make identical time-marks on all seismograms, but it is recognized that this would require a station, or group of stations, for this purpose alone, and that these stations would need to be powerful long-wave stations to avoid skip-distance and fading trouble. It is, therefore, probably impracticable at the present time. Recognising this, it is regarded as desirable, and probably practicable, to have time-signals broadcasted at intervals of one hour throughout the day, or failing that, at intervals of two hours. The sending of time-signals at longer intervals than two hours, but more frequently than at present, while affording some improvement, would hardly meet the true requirements for scientific purposes. In the absence of the ideal arrangement, it seems urgently desirable that the signals be sent out as frequently as once an hour. I hope strongly that an arrangement of this kind may be effected.

(March 31, 1931)--It has occurred to me that in my letter of March 11, in reply to yours of March 5, discussing the desiderata for the broadcasting of time-signals, I made no mention of wave-length.

It is very desirable that the stations engaged in the broadcasting of time should employ wave-lengths fixed by quartz-oscillators, or in some other way, so that

there will be no variation in wave-length from day to day, thus allowing for the reception of the time-signals by automatic apparatus which will then function without attention except at considerable intervals. I raise this point because there has been at times apparently slight variation in wave-length in the sending by western stations which has required us to make frequent tuning-adjustments.

B. Gutenberg, California Institute of Technology, Seismological Laboratory, Pasadena, California (March 16, 1931)--I regret very much that it will not be possible for me to attend the meeting of the American Geophysical Union. I am not familiar enough with the work of the Union to give any views, but especially in the question concerning the broadcast of time-signals it would be mostly desirable to have time-signals every minute. If it is not possible to realize this, accurate time-signals are desirable as often as possible. The errors of these signals must be controlled and must be published at a place where the seismological stations can easily find them.

ESTABLISHMENT OF WORLD-TIME

F. W. Lee

The following signal time-service is offered for the consideration of the Union as a basis for the establishment of a system of international or world-time, the important need for which is daily becoming increasingly evident.

That our basis of physical measurement rests upon determination of mass, space, and time is idiomatic. Standard units of mass and space may be made available and compared without much effort--witness our standardization-laboratories. In many physical measurements, however, a standard unit of time which in three-dimensional space cannot be carried about as a standard gram or centimeter is of utmost importance. Synchronous observations at widely separated points under the present system are not practical and cannot be made except at great expense. A zero-line so to speak from which to measure time everywhere at the same unit-intervals does not exist. Phenomena under present conditions which require synchronous observations are also difficult to make with a high degree of accuracy. The second, which once was thought to meet our needs as the smallest unit of time, has become an inordinately long interval for many physical measurements and one-millionth of a second or micro-second now often proves a more convenient unit. "Simultaneous-time" observations to an accuracy of at least one micro-second would be very acceptable at the present moment in many time-measurements.

While the signal time-service as rendered by the Naval Observatory has been effective it has one great fault in that it is not functioning continuously. An improvement of major importance would be secured if its service could take the form of a continuously emitted electromagnetic or wireless wave with a cycle adjusted to constancy by proper astronomical coincidences and corrections.

The frequency or wave-length selected for a service of this nature should be one which always would insure positive transmission, preferably of the order of twelve kilocycles or a wave-length of about 25,000 meters. This could also be supplemented with another frequency of 1,200 or 12,000 kilocycles acting as a harmonic of twelve kilocycles. Furthermore, these frequencies could be further modulated at 6,000 cycles and also at 60 or 50 cycles per second. Whether it is desirable to use harmonics of integer or fractional values should be carefully studied since each have their respective advantages.

Because of the attenuation which these waves suffer it would be necessary to augment their signal-strengths at various predetermined stations. It is seen that it is desirable to choose a wave-length such that when passed around the Earth it would reach the original station in phase with the emitted signals. Just how the Earth responds to various frequencies in a standing or traveling-wave condition must be made the subject of more study.

Such a combination of constant-frequency wireless waves distributed from various cardinal places over the Earth would supply "world-time."

The ease, usefulness, and cheapness with which a system like this could be utilized is self-evident. A system of this nature would control commercial power-frequencies by directly acting upon the governors of the prime movers. It would serve to synchronize broadcasting stations and keep them on their proper wave-length automatically. It would control the speed of scanning discs or similarly acting television-devices. It would prove invaluable to gravity pendulum-observations and seismology. It would also save much expense in time recording and time-reproducing systems in many research-laboratories.

Thus at one time it would aid in the most difficult relativity experiments in astronomical observations and at the same time run the kitchen-clock.

"World-time" is an economic necessity as well as a needed tool of precision in the hands of scientists. The world would benefit by its establishment.

U. S. Bureau of Mines,
Washington, D. C.

THE SERVICE AVAILABLE FROM THE STANDARD-FREQUENCY TRANSMISSIONS OF THE BUREAU OF STANDARDS

J. H. Dellinger

(Publication approved by Director of Bureau of Standards of U.S. Department of Commerce)

This paper sets forth the possibilities of standard-frequency radio transmissions in connection with time-standards. The subject is approached from the radio viewpoint but the usefulness of the transmissions to certain classes of needs for time-service is apparent. A clear distinction should be understood at the outset, that between calendar time, on the one hand, and time-intervals or rates, on the other. There is no known method by which calendar time can be given other than by the furnishing of time-signals, of which the United States Naval Observatory time-signals are the outstanding example. As for the second class of service, it is abundantly evident that time-signals destined for the first purpose could never be given at sufficiently frequent intervals to serve all the needs for accurate standards of time-differences or rates.

Since the frequency of an alternating-current or a radio wave is dimensionally the reciprocal of a time, a standard-frequency can serve as a standard of time. Such a standard is a time-standard of the second type, that is, a time-rate standard. It is, moreover, an ideal standard of time-rate because it is by its very nature instantaneously available. In practice, a standard of known frequency serves as a time-rate standard by using the reciprocal of the frequency, and serves as a standard of time-duration or difference merely by providing a means for counting the number of alternations and multiplying by the known frequency. If the frequency-standard is of adequate accuracy, it can provide a time-duration standard desired by some classes of scientific observers, jewelers, and others interested in a short time-interval, which they can obtain in no other way.

Whether these theoretical considerations can lead to a time-rate service of practical value depends upon two things: (a) The existence of a standard of frequency of adequate accuracy, and (b) means of making this frequency-standard available wherever desired. Both conditions have now been fulfilled or are rapidly on the way to fulfillment. In respect to (a), accuracy, the national primary standard of radio frequency, maintained by the Bureau of Standards, is of the same order of accuracy as the absolute time-service provided by the Naval Observatory signals. This standard and its accuracy are described in another paper on this program. In brief, the accuracy of the standard is much better than a part in a million, and it is expected to be a part in ten million.

As to means of making the national primary standard of frequency widely available, the radio transmissions of standard-frequency waves by the Bureau of Standards provide this. The Bureau has transmitted radio waves of standard-frequency regularly ever since 1923. These transmissions are at scheduled times announced and published

in advance. Their accuracy has at all times been more than adequate for the needs of radio service. These needs have become more and more rigorous, and the accuracy of the Bureau's standards and of the transmissions has progressively increased. The accuracy has now become so good that the standard-frequency transmissions serve adequately every purpose of time-rate standards as well as frequency-standards. The technique of the transmissions has also improved; the waves actually transmitted are held constant to about the same accuracy as that of the primary standard itself, upon which the transmissions are based.

It is the aim of the Bureau to make these transmissions with adequate power and on suitable frequencies to provide reliable frequency-standards and time-rate standards everywhere in the United States. The nature of radio-wave transmission is such that when this is achieved, a fair service of the same kind will be rendered throughout a large part of the world; and it may be possible eventually to make the service actually reliable and available throughout the whold world. During the present year the transmissions are made every Tuesday for two hours in the afternoon and two hours in the evening. Arrangements have been made to extend this so as to provide the same service every day instead of only one day a week. It is expected that this extended service will be on the air within the next year. The program contemplates eventually making the service continuous all day every day. If this goal is achieved a frequency and time-rate service will then be available at all times and places.

A few details of the transmissions may be of interest. At the present time they are carried on with a transmitter of one-kilowatt power. In the new transmitter about to be installed this will be increased to 20 kilowatts, which should be adequate. The principal transmissions are on a frequency of 5,000 kilocycles per second. They have been received and utilized satisfactorily practically everywhere in the United States, including the west coast and Alaska. The frequency mentioned is a satisfactory one for night use. It is expected to use 15,000 as well as 5,000 kilocycles for the daytime transmissions. Some transmissions are also made on a variety of other frequencies, but the 5,000- and 15,000-kilocycle transmissions are expected to furnish the principal service. Other frequencies, such as 10,000 and 20,000, may be used if found necessary to cover greater distances reliably. Besides the carrier-frequencies mentioned, it is expected to have the transmitted waves carry one or more modulation-frequencies. The frequencies tentatively in view are 5,000 cycles per second and 60 cycles per second. The former will have a variety of uses for radio and physical purposes. The use of a 60-cycle modulation is discussed further below. Suggestions from prospective users of the service as to the most useful modulation-frequencies would be welcome.

The applications of this service are many. It has been used in the past principally for the calibration of standards of radio frequency used by radio laboratories, manufacturers, and transmitting-stations. This serves a most useful purpose in putting the radio stations of the country more and more on a single frequency-basis and thus contributing to the minimization of radio station-interference. It is expected that the service will be used more and more for direct control of the frequency of radio transmitting-stations. Stations can receive the waves and operate amplifying and frequency-changing apparatus so as to directly control the frequencies of the waves which they in turn emit. As this application develops, one of the most fruitful results is expected to be the synchronization of broadcasting stations. When two or more broadcasting stations operate on a frequency which is accurately the same instead of only approximately so, heterodyne-interference is eliminated and the service-area of such stations is greatly increased. Such synchronizing is carried on to a very limited extent at the present time by means of a synchronizing frequency carried by wire-line, which is a very expensive process.

Another purpose served by the transmissions is the furnishing of a convenient means of intercomparison of the principal frequency-standards and clocks of the world. The fact that these transmissions give a standard which is available from instant to instant instead of available only by integrating processes over long intervals (as in the case of time-signals) makes them advantageous for this purpose. If it is found useful, a special signal can be put on the standard-frequency transmission at prearranged times to indicate a specific summation of a number of cycles, thus facilitating the use of the transmissions as time-duration signals. Persons engaged in physical measurements, geodetic, seismological, and similar work, can by the

use of simple receiving-equipment, receive the signals and utilize them by means of chronographs, etc., for whatever time-rate or time-duration purposes they desire.

Mention has been made of the plan to have the transmitted waves carry certain modulation-frequencies. One of the possible applications is the synchronization of television-apparatus. An audio frequency of a suitable value for this purpose could be included as a modulation-frequency. The operators of television-systems could receive the waves and utilize this modulation-frequency for the synchronization of rotating apparatus both at the transmitter and the receivers for visual broadcasting. No definite plan has been worked out on this and it remains to be seen whether this would be a useful field of application. Another field of synchronization which can be served by these transmissions is that of the electric power-stations. The interconnection of 60-cycle power-plants throughout the country would be facilitated by a universally available 60-cycle frequency which would give a means of control whereby different generating plants could be kept accurately in phase. The same service would insure that electric clocks operated by the power-systems would keep accurate time.

Another purpose served by the standard-frequency transmissions is one having no direct relation to time-service but of considerable importance in radio. Since these transmissions will be available a large part of the time and will be of a type suitable for reception and measurement, they will serve as a basis of research on the behavior of radio waves. Cooperative measurement-programs of wave-transmission will be facilitated by the regularity and availability of these transmissions.

In conclusion, the standard-frequency transmissions of the Bureau of Standards have a growing value in the perfecting of radio technique and also furnish a reliable and accurate basis of determining time-rates and time-intervals. The accuracy required is already assured. The reliability and availability of the service is being constantly improved. Good progress is being made toward the ultimate goal of making the service universally available. It is hoped that the outline here given will be productive of suggestions both as to the operation of the service and as to possible applications of it. Such suggestions will be particularly welcome while the system is still in process of development.

U. S. Bureau of Standards,
Washington, D. C.

THE ACCURACY OF THE PRIMARY FREQUENCY-STANDARD OF THE BUREAU OF STANDARDS

Charles G. McIlwraith

(Publication approved by Director of Bureau of Standards of U.S. Department of Commerce)

The problem of maintaining a frequency-standard resolves itself into two main parts. First, we must have an oscillating system which maintains a frequency sufficiently steady so that its fluctuations are negligible in comparison with the errors of measurements made against it. Second, we must have some way of finding out how constant the frequency is, and what is its absolute value.

The vibrations of a quartz-plate, when all the conditions are maintained constant, are very nearly constant in frequency. The primary frequency-standard of the Bureau of Standards consists essentially of a group of four piezo-oscillators, each having a frequency of 100 kc per second.

The quartz-plates are toroidal in shape, since that form has a smaller temperature-coefficient of frequency than the solid disc. The plates are triply thermostated. The plate is in a heat-attenuating layer, surrounded by an equalizing layer, in which the thermostat is placed. The whole oscillator-circuit, with its associated amplifiers, is placed in a box which is roughly thermostated, and finally the room is temperature-controlled. The temperature of the quartz-plates varies less than $0^{\circ}01$ C over a period of months. Since air-pressure has a marked effect on the frequency of a quartz-plate, each one is placed under a bell-jar and thus protected from this source of variation. Variation in the voltages supplied the oscillator is another cause of fluctuations of frequency; hence an automatic voltage-control operates on both filament- and plate-supplies. Finally, the oscillators are swung from

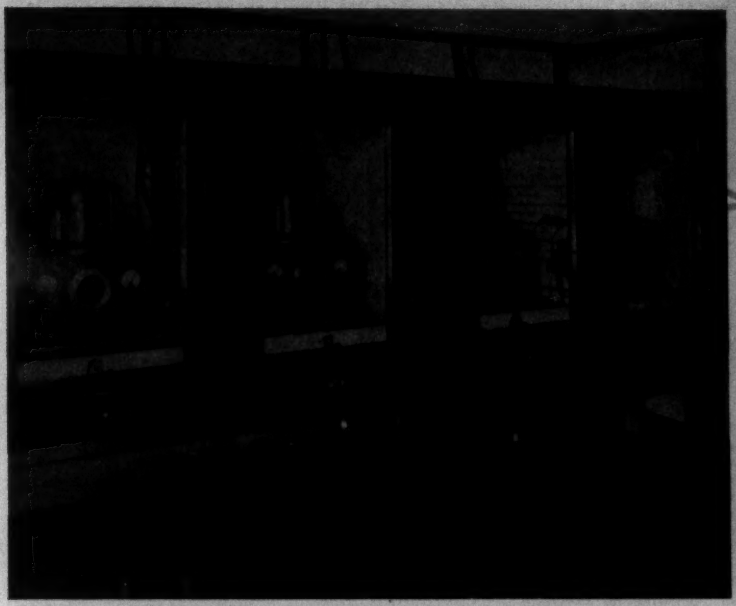

Fig. 1--The four piezo-oscillators of the primary frequency-standard

Fig. 2--The quartz-plate and the plate-holder, disassembled

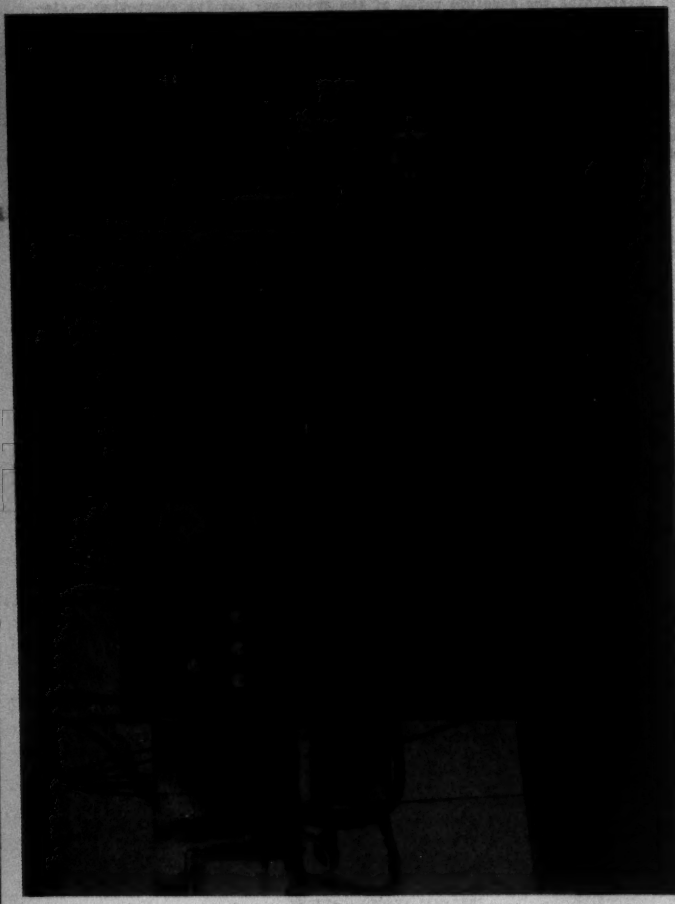

Fig. 3—The apparatus used in controlling and measuring the frequencies of the piezo-oscillators

springs to protect them from mechanical shock, to which the type of quartz-plate mounting used makes them very susceptible.

Figure 1 is a view of the four oscillators in their temperature-boxes. This view was taken before the shock-mounting was applied.

Figure 2 shows the quartz-plate and its mounting. The ring of quartz hangs on a bakelite-peg passing through the hole, the axis being horizontal. This type of mounting has the advantage of giving small damping of the plate, but is very susceptible to mechanical shock, as the plate is not clamped in any way. The air-gap between the quartz-plate and each electrode is maintained constant by a Pyrex ring, and provision is made for adjusting the frequency of the plate by changing the air-gap.

For determining the absolute value of the frequency and its short-time variations, the apparatus on the racks shown in Figure 3 is used.

The first three oscillators are used as alternative standards, the fourth as a reference-point against which to check the other three. Frequencies from the first three and the fourth are modulated together in a device known as the beat-frequency indicator. There the difference-frequencies between the first and fourth, second and fourth, and third and fourth oscillators are obtained and are indicated on the three small milliammeters on the left. They also operate a recording-mechanism by means of which a graphic record of the beat-frequencies is obtained. In this way frequency-fluctuations over periods of the order of fifteen minutes are measured.

To determine the absolute frequency, a device known as a submultiple generator is used. It consists of a series of four multivibrators, in which the original frequency of 100 kc per second is stepped down to 1 kc per second, losing nothing in accuracy by the process. The 1,000-cycle current is then amplified and drives a synchronous motor which in turn drives a clock. The whole system is so designed that if the quartz-plate has a frequency of exactly 100 kc per second, the clock keeps accurate mean solar time. Then the problem becomes simply that of determining the rate of the clock, which is done against radio time-signals.

As a result of this rather devious process, our frequency-standard has become an accurate clock as well, and not only furnishes frequencies at all the multiples of 10 up to 100,000 but can measure an interval of time of almost any length.

The precision obtained from this equipment is rather high. The result of about twenty months of use shows that during undisturbed operation, the random variations of one oscillator relative to another, over a period of an hour or less, are certainly less than one part in ten million, more probably about three parts in one hundred million.

The absolute frequency, being dependent on time-comparisons, is less easy to obtain precisely than the relative changes in frequency. However, the frequency is always known as well as one part in a million, and experience is showing that the uncertainty is about two parts in ten million.

The linkage between the vibrating quartz-plate and the clock is a rather long one, but it has the advantage that slip in the mechanism is instantly detected. In fact an abrupt phase-shift of much less than a cycle will cause the clock to stop and thus advertise the accident.

The evidence is thus that the piezoelectric "clock" is of the same order of precision as the best mechanical clock. The mechanism of the piezoelectric outfit is quite complicated, and more liable to failure than the mechanical clock; so where long-period timekeeping only is needed, the latter is to be preferred. But the piezoelectric system is a far more versatile instrument and can, without any difficulties of design, be made to give accurate intervals of any length desired, from about one millionth of a second up to hours.

U. S. Bureau of Standards,
Washington, D. C.

INFORMAL COMMUNICATIONS

C. W. Horn, National Broadcasting Company, New York, New York--I am very glad to be present and hear these comments on the value of time-signals, because of the interest that those of us in the radio game have in accurate standards--all of which are based on accurate time-measurements. I was interested in listening to the reports of difficulties in checking time in the field and on location, and the demand that was made for more frequent time-ticks by radio. I am afraid that the broadcasting organizations are not able to furnish such a time-service unless they supplement the Naval Observatory time-tick. It may be possible for some stations to do as the Westinghouse station KDKA is doing, that is, send a time-beat every hour on the hour right through the program. In the case of Westinghouse, they are using their own clock. In order

to make such a service of value to the checkers in the field, these time-beats must originate at the Naval Observatory, which would require wire-lines and suitable correction-apparatus in order to prevent relay-lag. However, there is quite an expense involved, which it is feared the broadcasting companies are not in a position to bear.

The public is becoming accustomed to accurate time, much more so than they have been in the past. In industry--in the fine scientific work that is being done--we are finding a great need for accurate time to within a fraction of a second. This need will grow constantly as we progress.

In broadcasting, we have, what our operating men call, "synchronization-periods." In the case of my company (National Broadcasting Company) the clocks in its various studios in New York, Chicago, Washington, San Francisco, etc., are synchronized to within a few seconds. This is made absolutely necessary because our networks are frequently broken into different units and operate independently, whereas, at other times, they are combined. Programs must start and stop practically within a second or two in order that no overlapping or confusion results. This is just another example of the necessity of having accurate time-standards, although in this case, we are not concerned with accuracies to within a fraction of a second. However, in the case of controlling frequencies of transmitting-stations, we find it necessary to use standards that are accurate within one part in a million--all of which, of course, are checked back to some accurate time-standard. Therefore, accurate time is a very fundamental requirement.

H. A. Affel, American Telephone and Telegraph Company, New York, New York--I do not think that we, who came here as your guests from the Bell System, did so with the intention of offering any advice; rather we had in mind listening to see to what extent we could be of service in connection with your problems.

As you probably know, the Bell Telephone Laboratories have done considerable work in developing accurate frequency- and time-standards, particularly with quartz-crystal oscillators. Dr. Marrison is better qualified than I am to discuss this subject.

We have also given considerable thought to the possible use of wire-circuits for disseminating time-impulses or standard-frequencies. Wire-circuits used for this purpose are, of course, in a sense, competitors of the radio methods which have been described by Captain Hellweg and Dr. Dellinger. We are at the present time cooperating with radio companies by transmitting standard-frequencies over wire-circuits for the purpose of synchronizing broadcast-stations at different points. This is a modest start in the direction of what can eventually develop into something which has more widespread uses. I should, therefore, like to know to what extent a wire-distributed standard-frequency service can be made use of in any of the work which the speakers have described today. From my own observations it would appear that it might be particularly useful in connection with the seismological work referred to by Dr. Macelwane.

I might add that there are, of course, several Bell System companies who are giving time-of-day service to subscribers. The accuracy requirements in this case are obviously not of the same order as required by the different activities which have been described by the speakers.

W. A. Marrison, Bell Telephone Laboratories, New York, New York--As some of you know we have, in the Bell Telephone Laboratories, primary standard-frequency equipment similar to that now used in the Bureau of Standards. This equipment was described in the Proceedings of the Institute of Radio Engineers for July 1929. The accuracy that we have obtained has been of the same order as that reported by Dr. McIlwraith, except that the continuity has been perhaps a little better, due to having complete duplicate power-equipment, and having therefore the ability to continue through even major disturbances in the primary power-source. On the basis of months of observation, the expected day-to-day accuracy is about two parts in ten million. The determination of this has been limited somewhat by the accuracy of the time-comparison equipment. On the basis of comparisons between separate standards maintained in the same laboratory, the accuracy appears to be even better than this.

Our chief interest in standard-frequency equipment at this meeting is for the measurement of time and related quantities. I believe that the crystal-clock may have some important applications in this field.

One such application is for the control of accurate time-signals. It is possible, with a constant frequency and a synchronous motor, to obtain very uniform rotation. If a sectored disc, driven in this way, were used to interrupt a beam of light received by a photoelectric cell, the resulting electrical signal could be amplified and modulated directly on a radio-carrier frequency or transmitted any distance by wire-line. Such a method for the transmission of time-signals does not require any mechanical relays and would provide a signal which, at the source, would be timed in phase with the controlling element to within a fraction of a millisecond. Mechanical errors in the transmitting-apparatus would thereby be avoided completely.

The crystal-clock could be rated in terms of star-observations directly or in terms of the usual pendulum-clocks which in turn are checked by the stars. In the latter case the comparison with the clocks can be effected with no appreciable error. In fact the crystal-clock can be adjusted without error by any desired predetermined amount, so that time-signals could be produced having the highest absolute accuracy with which the time can be determined at any present time. Some further ideas on this are given in a paper, "The crystal-clock," published in the Proceedings of the National Academy of Sciences for July 1930.

When it is desired, as is now frequently the case, to make daily measurements accurate to say one part in ten million by means of time-signals, an accuracy of approximately 0.01 second is required. Such measurements would be aided materially if signals could be employed that are always within 0.01 second of true time, thus avoiding, for most purposes, the necessity for a table of time-signal corrections and the consequent delays in the reduction of data.

Another application concerns the use of a frequency standard in apparatus for the accurate timing of events, that is, as a chronograph. Since the frequency at which it would be desirable to obtain time-signals depends largely on the constancy in the rate of the receiving chronograph, an improvement in this apparatus might be at least a partial solution to problems that appear to require more frequent transmissions. The constancy of crystal-controlled oscillators, and the ease with which a uniform rotation can be controlled from such an oscillator, point to the possibility that a crystal-controlled chronograph would be a useful tool for time and related measurements.

AMERICAN GEOPHYSICAL UNION

Twelfth Annual Meeting

REPORTS AND PAPERS

S E C T I O N O F G E O D E S Y

Washington, D. C.
April 30, 1931

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PROGRESS-REPORT ON THE ABSOLUTE DETERMINATION OF GRAVITY AT WASHINGTON, D. C.

Paul R. Heyl

(Publication approved by the Director of the Bureau of Standards of the United States Department of Commerce)

During the past year this project has moved forward, though perhaps not as rapidly as hoped and desired.

Of the two quantities to be measured in the determination of gravity, time and length, it is the latter which calls for the most careful preparation and execution, as upon it the precision of the result chiefly depends. The measurement of time can be carried to an accuracy considerably greater than that of length. The best that can probably be hoped for in a measurement of length in a vertical position, as with a reversible pendulum, is one part in a million, and to reach this unusual care will be necessary.

The three essential parts involved in the length-measurement have all been constructed of fused silica to eliminate difficulties caused by slight changes of temperature. It is not practicable to make vertical measurements in a water-bath, and in consequence all essential parts involved in this measurement must have as small a coefficient of expansion as possible. These parts are the pendulum itself, the standard scale and the backbone of the comparator which carries the micrometer-microscopes. The second and third of these parts are now ready for use, but some work still remains to be done on the pendulums.

It was found necessary to alter the original design and construction of the pendulums rather radically for the purpose of obtaining sufficient mechanical strength. In its present form each pendulum consists of a silica tube about 150 cm long, carrying two silica planes, upon which it oscillates in turn. The knife-edge, of silica, is fixed in the pendulum-support. By cutting or grinding off small portions from the lower end of the tube the times of swing on the two planes can be readily adjusted to equality.

As originally planned, the distance between these planes was to be measured by the usual procedure in the case of end-standards, but a little work showed that this method could not be used in this case. The results by this method are very sensitive to slight changes in focus, especially with a long-focus objective such as had to be used in our arrangement. Because of this difficulty the plan of procedure was altered to that usual with line-standards, and some further delay has been caused by the necessity of making the changes requisite to the carrying out of this new plan.

Three pendulums have been provided, of different diameters, to eliminate the bending-error, which is one of the large corrections in work of this kind. Their outside diameters are, respectively, 3.8, 4.4, and 5.0 cm, and their relative rigidities are as 1, 1.6, and 3. The mass of the largest pendulum is about 2.3 kg.

The part of the apparatus concerned with time-measurements is much farther advanced toward completion. Signals are drawn photoelectrically from the master-pendulum of a Shortt clock and transmitted without a mechanical relay or other moving parts to a neon-lamp which furnishes flash-signals for the timing of the pendulum.

U. S. Bureau of Standards,
Washington, D. C.

MEXICAN GRAVITY-STATIONS IN 1930 AND FIRST CALCULATIONS AND CORRECTIONS FOR TOPOGRAPHY AND ISOSTASY

Elfego Ruiz

(Translated by Earl S. Belote)

In continuation of the program of gravimetric work ordered by the Department of Geographic and Climatological Research during the year 1930, twelve gravity-stations were observed, all in the central plain of our Republic, besides the two determinations at the base-station in Tacubaya. The apparatus used was constructed by the firm of Berger and Sons of Boston, and consists of three invariable bronze pendulums, one-quarter meter in length and one-half second in oscillation, besides the thermometer-pendulum, coincidence- or flash-apparatus, interferometers, chronometers, etc., similar to those used by the United States Coast and Geodetic Survey, with which differences of gravity between two given places are obtained with great precision. Knowing the value of the intensity of gravity in Tacubaya, which was determined in 1912, with relation to that at Washington, all our observations have been reduced to obtain the differences in gravity between the stations in the field and the known value for the base-station at Tacubaya. The observations in this last city, made before and after each circuit, were for the purpose of testing the invariability of the mass of the pendulums and, consequently, the periods of oscillation and to correct the field-values for the resulting small difference. These are found in the "Table of the duration of one oscillation in Tacubaya" and in the curves of the periods of oscillation deduced from the same, which follow at the end of this article.

The twelve stations occupied during the year 1930, which correspond to the Tenth Circuit of gravimetric observations, are the following: Zacatecas, Zacatecas; Fresnillo, Zacatecas; Cañitas, Zacatecas; San Juan de Guadalupe, Durango; Ciudad Lerdo, Durango; Viesca, Coahuila; Parras, Coahuila; Saltillo, Coahuila; Matehuala, San Luis Potosí; Charcas, San Luis Potosí; Comonfort, Guanajuato; and Celaya, Guanajuato.

The time spent was four months, corresponding to a mean of ten days per station, the minimum time which, at present, has been achieved with the actual method of observation. This method consists essentially of the determination of the value of the period for each one of the three pendulums that comprise the equipment, giving two days for the first pendulum and one day for the other two, respectively; that is to say, four observations each nominally of twelve hours duration for the first pendulum and two (observations) for the others, or a total of eight observations in all. Each is independent of the others because the chronometer-comparisons are made twice a day when the time-signals from the Naval Observatory at Washington are received at noon and 10 p.m., 75° meridian time, at which times the corresponding pendulum "swings" begin and end. For the reception of these signals which are broadcasted by the radio stations NSS at Annapolis and NAA at Arlington, we have used short-wave receivers with a detector-tube and one step of audio-frequency amplification, Schnell circuit. These were constructed in our shops and up to the present they have given us good results. The method employed for the comparison of chronometers and signals has been that of coincidence, using for the purpose a chronometer, which we have called "vernier," adjusted so that it gains one second for each sidereal minute, that is, advances 61 seconds for every 60 seconds of sidereal time. This procedure, conceived and put in practice by Manuel Medina, Chief of the Department of Geography, and José F. Bracho, formerly Chief of the Section of Gravity, has given us excellent results, saving us time and making unnecessary the transportation and careful manipulation of the chronograph. By means of the accelerated rate of this vernier-chronometer, there are obtained, with good conditions of reception, up to twelve coincidences during the five minutes of mean time that the broadcast of radio signals covers, and, as the comparison of chronometers is made a little before and a little after the reception of signals, the whole operation can be made in approximately 20 minutes. The error with which a coincidence is estimated by a practical operator is at most one second, which guarantees that the error of the comparison, when eight coincidences have been taken, will be less than two hundredths of a second. By means of some rules or scales engraved for the purpose the chronometer-readings or the readings corresponding to the signal-times at the moment of coincidence shown on the vernier are afterwards derived.

The observations to measure the flexure of the support by means of the interferometer are made indiscriminately before or after those for the period and preferably at night, at the hours of greatest quiet. From two to four independent observations have been sufficient to obtain its value, the number depending on the difficulty of the observations.

With the aim of proving that the pendulum-apparatus had not suffered alterations with the passage of time or from the constant use to which it had been subjected, also to show the personal influence of the observer, or to note any geological disturbance in the vicinity of the station, it was ordered to repeat the observations made in the year 1926 by Mr. Bracho in Zacatecas, in the station built in the ex-convent on the hill of the Bufa. Both the condition and the method of observation were the same, except that the reception of non-rhythmic signals and comparison of chronometers were, in the first occupation, registered on the chronograph and in the second obtained by coincidences. The results were sufficiently in agreement as is seen in the following table.

Station No.	Name	Observed gravity	Probable error	Year	Observer
14	Zacatecas	978.089	- 0.001	1926	J. F. Bracho
49	Zacatecas	978.084	- 0.0005	1930	E. Ruiz

The construction of a special pier on which to place the pendulum-receiver for the observations was rendered unnecessary at the stations to which this paper refers by using the telescope of the coincidence-apparatus in a vertical position. This was accomplished by the use of a prism that deflects the light-rays through 90°, as adapted in the modern types of apparatus, but which here we had not been able to use. This method not only diminished appreciably the value of the flexure, but also saved time amounting to at least three days which are taken up by the construction of the pier and we were, therefore, able to observe three stations a month, as stated above. The pendulum-receiver is placed directly on the floor and the observer can observe while comfortably seated.

For the computation of the observations, there has been used a procedure simplified by Ricardo Toscano, Chief of the Computing Section of this Bureau, the development of which is explained in the record of the Section relative to this work.

At the end of 1930, the computations of the corrections for topography and isostatic compensation were begun, after a collection of topographic maps of the environs of the gravity-stations had been made and the contour-map of the Republic of Mexico to the scale 1:2,000,000 had been constructed for the purpose. A terrestrial globe was also obtained, upon which was fitted a spherical form of fine wire, marking the zones from the eleventh to the first. This wire frame was movable in such a manner that one of its diameters which is at the center of the zones could be made to coincide at the opposite end with the point on the terrestrial globe at which the gravity-station was located.

We have accepted the theory contained in Special Publication No. 10 of the United States Coast and Geodetic Survey entitled "The effect of topography and isostatic compensation upon the intensity of gravity" by John F. Hayford and William Bowie and have used the reduction tables there published for the different zones to obtain the corrections for topography and compensation. The grids or "templates" for the various scales of maps have been made and we have succeeded, at the time of this writing, in computing the corrections for nine stations and hope to finish the rest in a short time, as the work is already well under way. The lack of maps has delayed the completion of the work for some stations and perhaps has made the value of some of the corrections uncertain because of the lack of precision in calculating the mean altitudes of the compartments, although it is very probable that the final derived result for the compensation will be very near the true value.

Isostatic anomalies at gravity-stations in Mexico

(Condensed from table in original paper)

Station	Latitude	Longitude	Elevation	Isostatic anomaly
			meters	cm/sec^2
Tacubaya, Distrito Federal	19 24.8	99 11.7	2,299	-0.033
Zacatecas, Zacatecas	22 46.7	102 34.0	2,596	+0.004
Pachuca, Hidalgo	20 07.7	98 43.9	2,425	+0.009
Tulancingo, Hidalgo	20 05.0	98 22.0	2,155	-0.034
Tiro Hermoso (Piso 500), Hidalgo	20 08.4	98 40.3	2,264	+0.015
Tiro Hermoso (Boca.), Hidalgo	20 08.4	98 40.3	2,865	-0.001
Amecameca, Mexico	19 07.6	98 46.0	2,468	-0.026
Tlamacas, Puebla	19 04.0	98 37.5	3,885	-0.036

Direccion de Estudios Geograficos y Climatologicos,
Tacubaya, D.F. Mexico

GRAVITY AT THE STOCKHOLM MEETING OF THE INTERNATIONAL GEODETIC AND GEOPHYSICAL UNION

Walter D. Lambert

The Gravity Committee of the Section of Geodesy made several important decisions at Stockholm, all of which were in due course approved by the Section. (The name Section was later officially changed to Association.) These decisions may seem to relate to somewhat technical matters and to concern chiefly those persons who attend to the minute details of the various calculations but they are, in fact, fundamental enough to deserve mention here.

It should be explained that the speaker was not able to attend the Stockholm meetings and that, since the official account of the proceedings has not yet been published, the text of the decisions was obtained from personal letters. The interpretations here given are, therefore, personal rather than official.

Three decisions deal with the isostatic method of reduction. They are:

(1) The Committee recommends that the isostatic method be used for the reduction of observed values of gravity and that in the reduction both the direct effect and the indirect effect (the Bowie reduction) be taken into account. (See Bulletin Géodésique, No. 26, 1930.)

(2) For the sake of uniformity the Committee recommends that the calculation of the isostatic reductions be based on the Hayford zones.

(3) In order to render possible the study of other methods of reduction, it is desirable that published results should give the mean values of the elevations of the Hayford zones A to O inclusive and that the effects of topography and compensation be given separately.

The first decision recommending the isostatic method is obviously superfluous if isostasy itself, or any phase of it, is the subject of investigation. In such cases the isostatic method of reduction is inevitable. The recommendation presumably refers to investigations having for their primary purpose a study of the form of the geoid either as a whole or in part. The decision of the Gravity Committee to recommend the use of the isostatic method for such investigations means that the Committee believes the theory of isostasy to be at least approximately correct. If we had a close network of stations all over the globe, almost any method of reduction could, with sufficient labor of calculation, be made to give the actual figure of the Earth, but under present conditions there is obviously a distinct advantage in adopting a method that corresponds to actual conditions in the Earth's crust.

Every gravity-station is necessarily taken as representative of the region in which it lies, a region that may be said to extend half way toward every one of the surrounding stations. If the topography around a given gravity-station is exceptional, the station may not be fairly representative of this region. The use of the isostatic method tends to reduce the possibility of seriously misrepresenting the area controlled by the station in question, an area that may under present conditions be very large.

The isostatic reduction, as hitherto applied, has not been complete. The Bowie term is a reduction from the actual geoid to the isostatic geoid. Up to this time it has not been applied in the current practice of reduction but it is expected that the Coast and Geodetic Survey will soon be in a position to apply it.

The text of the second recommendation provides the substance of its own explanation. "For the sake of uniformity" it recommends that the Hayford zones be used. The dimensions of the outer zones may seem somewhat arbitrary but they were in fact adopted to simplify the calculation on the hypothesis of a particular law of compensation by setting up a simple proportionality between the map-reading and the computed resultant correction. This simplification disappears entirely if a different law of compensation is adopted, but so much work has been done with the Hayford zones that it seems desirable to continue using them. For the inner zones the dimensions were taken small in order to represent adequately the topographic effect. If in any particular case a zone or compartment seems too large or inconvenient in shape, the logical course would be to subdivide it.

The third recommendation also explains itself. It asks fuller details, so that the map-readings made for computing the topography may be available to test out other forms of the theory of isostasy. It asks these details for the nearer zones only. The recommendation might have gone further and asked similar information for the outer zones also. For these outer zones, however, the information about the topography may readily be inferred from the corrections themselves--that is to say, readily inferred but only roughly inferred; hence the suggestion that it might be desirable to extend the scope of the request and ask for the map-readings for the outer zones. Even for the inner zones further information is sometimes desirable, particularly for a station situated in rugged country. For such a station it is desirable to know the elevations compartment by compartment instead of merely the average elevation of all the compartments of a zone.

Another set of decisions involved the adoption of a standard formula for theoretical gravity, based on the International Ellipsoid of Reference. The proposals for such a standard formula were made by this very section to the Prague meeting of the International Union of Geodesy and Geophysics, but the Gravity Committee at the Prague meeting did not feel ready to act favorably on them. At Stockholm, however, chiefly through the efforts of Italian geodesists, the Gravity Committee and the Section of Geodesy approved the substance of the American proposals. These proposals and the accompanying explanatory text read as follows:

"A consideration of the advisability and practicability of adopting a standard gravity-formula and of whether or not such a formula should be based on the adopted International Ellipsoid. Explanation--Helmert's formula of 1901 for theoretical gravity has been much used in collections of gravity-data, but this formula involves a flattening of the Earth different from that of the adopted International Ellipsoid and implies a spheroid of reference that is not an exact ellipsoid of revolution but one slightly depressed in middle latitudes.

"In studying the figure of the Earth by gravity-methods it seems desirable to use the same surface of reference as in studying it by deflections of the vertical, in order to make results of the two methods readily comparable. The advantage of using a gravity-formula based on the adopted International Ellipsoid seems to outweigh the disadvantage of having to recompute the gravity-anomalies that have already been calculated by Helmert's formula of 1901.

"The gravity-formula based on the adopted International Ellipsoid is suggested chiefly for problems connected with the figure of the Earth. For other purposes, geological or geophysical, it may well be advantageous to use some other formula or formulas.

"When the adopted International Ellipsoid is made the basis of the gravity-formula, the values of b_2 and b_4, the coefficients of $\sin^2\varphi$ and of $\sin^2 2\varphi$ (φ = geographic latitude), are fixed, but not the value of γ_E, gravity at the equator. (The type of formula referred to is γ_o = theoretical gravity at sea-level = $\gamma_E(1 + b_2 \sin^2\varphi - b_4 \sin^2 2\varphi$.) The value of γ_E must be determined and adopted according to the best evidence available."

This statement of the Section of Geodesy of the American Geophysical Union makes it plain that the underlying reason was to render conclusions as to the figure of the Earth derived from gravity-data directly comparable with those derived from deflections of the vertical. It is specifically stated that other formulas may well be used to advantage for purposes other than the comparison of the results of determining the figure of the Earth by two different methods. It was certainly not the purpose of the Gravity Committee at Stockholm to seem to fix for all time the formula for theoretical gravity and thereby to discourage further investigations of the constants of the gravity-formula and the ellipticity of the Earth.

The Gravity Committee at Stockholm, in order to complete the specification of the constants of the gravity-formula, adopted as the value of gravity at the equator 978.049 cm/sec^2, a value based on the investigations of W. Heiskanen (Ist die Erde ein dreiachsiges Ellipsoid? Beitr. Geophysik, Leipzig, v. 19, 356-377, 1928, especially 375-376).

The formula for gravity on the surface of an exact ellipsoid of revolution that is at the same time a level surface under the combined effects of mass-attraction and rotation, or indeed gravity at any point outside of such an ellipsoid, may be written in closed but complicated form, but with sufficient approximation it may be written for the International Ellipsoid of Reference in the more familiar form

$$\gamma_o = 978.049\ [1 + 0.0052884\ \sin^2\varphi - 0.0000059\ \sin^2 2\varphi]$$

The constants within the square brackets are determined from the flattening of the International Ellipsoid of Reference, namely, 1/297, and the known rate of rotation of the Earth. This formula is of the same type as the Helmert formula of 1901, which it supersedes as the standard formula for international use. Helmert's formula is

$$\gamma_o = 978.030\ [1 + 0.005302\ \sin^2\varphi - 0.000007\ \sin^2 2\varphi]$$

The increase in the first coefficient 978.049 as against 978.030 represents a general increase in the value of gravity; this change seems fully justified by recent developments. The change in the second coefficient represents in the main a change in the flattening from 1/298.2 to 1/297 but also a change in the assumptions about small quantities of the second order. The coefficient of the term $\sin^2 2\varphi$ is entirely dependent on quantities of the second order. This term is omitted in many of the gravity-formulas hitherto used. If this term is omitted, the surface of reference is not in strictness an exact ellipsoid, but a spheroid of revolution that rises in latitude 45° to a maximum elevation of about 13 meters above an exact ellipsoid having the same axes as the spheroid. Helmert's formula of 1901 corresponds to a spheroid depressed in latitude 45° by about three meters below an exact ellipsoid having the same axes. The coefficient 0.000007 in Helmert's formula is determined not from observation but from mathematical theory based on the assumption that the form of the geoid is that of a uniformly rotating mass of liquid in hydrostatic equilibrium. The exact value of the coefficient depends on the variation of density within the liquid but all reasonable assumptions give nearly the same value, 0.000007. This coefficient is seen to differ slightly from the corresponding coefficient in the formula for gravity on an exact ellipsoid and the latter figure is, therefore, not one of exact hydrostatic equilibrium. The deviation from equilibrium is, however, slight.

Instead of using as a standard of comparison a spheroid having the same axes as the exact ellipsoid, it is better to use a spheroid having the same volume and the same mean density. If we take this point of view, the spheroid in hydrostatic equilibrium will lie about 2 1/2 meters above the exact ellipsoid at the pole; the two surfaces will intersect between latitudes 59° and 60°; the spheroid will then drop below the ellipsoid, attaining a maximum deviation of about one meter in latitude 41°; it will intersect the exact ellipsoid in latitude 20° and then rise above it to a maximum ele-

vation at the equator of about one meter. The undulation just described is represented by a spherical harmonic of the fourth degree. These figures are deviations of one level surface from another. To produce these deviations some variation in the distribution of mass is needed. If we consider this variation in mass to be represented by a surface-layer of positive or negative density, the thickness of an equivalent amount of ordinary rock would be in this case about six times the deviations given above, that is, a maximum thickness of about 15 meters at the pole and about six meters in latitude 41° and at the equator. (These figures are based on the work of Wiechert, Ueber die Massenvertheilung im Innern der Erde, Nachrichten von der Konigl. Gesellschaft der Wissenschaften zu Göttingen. Math. Phys. Kl., 221, 1897; more elaborate calculations by Walter Klussmann, Wiechert's pupil, published under a somewhat similar title and leading to about the same figures are given in Beitr. Geophysik, Leipzig, v. 14, 1, 1915-18.)

In view of the strength of the Earth's crust, loads such as this are negligible even in the refined investigations of isostasy, the more so since the amount of the load varies so slowly. It is the abrupt variations in the amount of load that tend to produce strain in the crust beyond its ability to sustain. The rate of change in the load in going from one gravity-station to another nearby where the gravity-anomaly is changing rapidly involves far greater departures from equilibrium and far greater stresses than those involved in the use of an exact ellipsoid as the surface of reference instead of a figure of hydrostatic equilibrium. Moreover, as stated in the American explanation, the new International formula is intended rather for investigations of the figure of the Earth than of isostasy.

In order to put into effect the decision of the Gravity Committee a set of tables for theoretical gravity on the new basis has been computed at the office of the Coast and Geodetic Survey and will shortly be published. It is intended to include with these tables some account of the theoretical developments on which they are based. Prof. Cassinis of Pisa, Secretary of the Italian National Committee on Geophysics, who was one of those who worked for the adoption of the new International formula, has published some interesting theoretical developments and is also at work on tables.

As has already been stated, it is hoped and expected that there will soon be an opportunity to attack also the problem of providing tables for the Bowie reductions in accordance with the recommendation of the Gravity Committee. Formulas for computing these tables have been given in the Bulletin Géodésique, No. 26, 1930.

U. S. Coast and Geodetic Survey,
Washington, D. C.

PROGRESS-REPORT ON GRADUATION AND CALIBRATION OF PRECISION-CIRCLES

Lewis V. Judson

(Publication approved by the Director of the Bureau of Standards of the United States Department of Commerce)

Several years ago the Bureau of Standards purchased a precision circular dividing-engine and a circle-testing apparatus. The need of the geodesist for more precise circles for first-order theodolites was one of the principal reasons for purchasing this equipment as I explained in a paper which I presented before this Union in 1926 (see Transactions, pp. 36-38). Since that time considerable work has been done with this equipment. Much more time was occupied in the preliminaries than had been anticipated. Modifications of both instruments were found necessary and desirable. Circles were then graduated and tested at the Bureau some time later. Although no errors were found in excess of two seconds, and there are indications that the actual errors of graduation were much less than this, field-measurements using the circles were reported as indicating the presence of much larger errors in the graduation. Although confident that the circles had been graduated with a high degree of accuracy, and that our calibrations of the graduations were also precise, it seemed advisable to wait until something more definite could be stated before making any progress-report. During the past year, however, enough information has been obtained to warrant a report at this time.

It is not my purpose at this time to present a scientific paper showing in detail the numerous measurements made by members of the Bureau of Standards and of the Coast and Geodetic Survey, but rather to present in outline what we have found and what plans are being made for future work. I would here express my appreciation of the painstaking manner in which my assistant, B. L. Page, and other members of the length-section have taken the many observations which have been required.

A nine-inch circle, designated as No. 3, for a first-order Parkhurst theodolite, is the circle on which our attention has been especially focussed. This circle was graduated September 26, 1929, two days after a similar circle No. 2, which has been in successful field-use. The conditions of graduation were apparently excellent in both cases. Calibrations made in April 1930 by members of the Bureau of Standards and in July 1930 by members of the Bureau of Standards and the United States Coast and Geodetic Survey showed circle No. 3 to be accurate, certainly within two seconds. But as this was not in accord with field-observations, arrangements were made in January 1931 for the Coast and Geodetic Survey to make a series of tests at the Bureau of Standards by sighting upon six collimators, using the circle in a theodolite which had given satisfactory field-service. Although the mounting of the equipment was not entirely satisfactory in every respect, the tests did demonstrate a systematic error which seemed to be in the circular graduations. The circle was then mounted on the Bureau's testing-equipment and these errors were found in the circle. Measurements also showed the graduations to be definitely "out of round," approximately in the shape of an ellipse. Measurements on circles graduated on this dividing-engine showed some to be circles and some ellipses. The amount of the ellipticity is as much as 0.05 mm and is more than the table of the dividing-engine can move laterally if the vertical spindle of the instrument is elevated a millimeter or more above its normal position.

These measurements showed unmistakably that there was an actual change in the circle. This has been verified in various ways, namely, by continuous changes in this circle while being kept at constant temperature, by rather good evidence of change even during the short period of time during which the collimator-tests were in progress, by an observable amount of warping in one circle, and possibly also by the fact that an ungraduated disk from the same source as the 9-inch circles and stated to have been originally machined to a true circle is now elliptical by about the same amount as the graduated circles.

It therefore seemed desirable to obtain the data in regard to the heat-treatment which the circles graduated by the Bureau have had, and also in regard to the machining, etc. This was done and sufficient data were received to make it clear that the heat-treatment was inadequate and that there were ample causes for dimensional changes of the castings. A program of fundamental research is therefore planned at the Bureau of Standards to study the composition, casting, heat-treatment, and machining of precision-circles as well as to make further improvements in their graduation and calibration.

The Bureau's first suggestion is to make a metal pattern of a modified design for circles to fit the Parkhurst 9-inch first-order theodolite. From this pattern there will be cast circular discs of bronze and other materials. These will be heat-treated by heating uniformly in a muffle-furnace and allowed to cool slowly, the temperatures used being those which previous experiments have shown to be most satisfactory. Tests will be made to determine what modifications, if any, are necessary to improve the stability of the circles.

As to the tests of a circle, I believe that the proper test of the circle itself is on an instrument especially designed for that purpose. There are times, however, when it is desirable to test a circle as a part of an assembled theodolite and I hope that plans can be carried forward for a specially designed collimator-system with a suitable pier for the mounting of a theodolite in a constant-temperature basement-room at the Bureau of Standards.

U. S. Bureau of Standards,
Washington, D. C.

FURTHER INVESTIGATIONS OF THE MOON'S INFLUENCE ON LATITUDE

H. T. Stetson

A study of the influence of the moon's position in the sky upon determinations of astronomical latitude, as exhibited in an analysis of the Gaithersburg and Washington observations, was presented at the Washington meeting of the American Geophysical Union in May 1930 (see Transactions, pp. 148-152). The present paper continues the discussion with additional evidence obtained from studies made at Perkins Observatory of the latitude-observations obtained at Ukiah, California, and longitude-observations obtained at Washington during the longitude-campaign of 1913-14.

The analysis of the Ukiah observations has been made for the years 1909, 1910, and 1911 with the able assistance of Miss Frances E. Naylor. A card-catalog was made of all observations, as was previously done for the Gaithersburg and Washington series, the stars being arranged in groups of two hours each in right ascension. Corrections were made for the main trend of the latitude-curve for the years in question, and the resulting latitudes plotted first against the hour-angle of the moon, computed for the mean sidereal time of the transit of the star-group. Running means of five points were taken at a time, the resulting graphs depicted in Figure 1. The magnitude of variation apparently due to lunar influence is of the order of 0.07, and

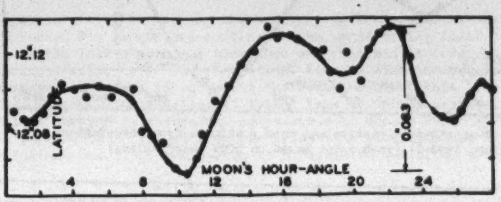

Fig. 1--Latitude-variation and moon's hour-angle from observations at Ukiah, 1909-11 (each point based on 500± observations)

compares favorably with the results previously published based on the Gaithersburg and Washington observations. A comparison of Figure 1 with the curves for Gaithersburg and Washington indicates a phase-difference for the time of maximum of about four hours in lunar time.

A transformation of coordinates from hour-angles and declination was made to azimuth and altitude, the resulting graphs being seen in Figures 2 and 3. As in the previous instance, the correlation between altitude and latitude appears to be of greater magnitude than in the correlation between hour-angle and latitude. Assuming that there may be a lack of symmetry east and west of the meridian, the positive and negative altitudes of the moon were divided into quadrants in order of sequence and a new graph plotted which is exhibited in Figure 4. The definiteness of the trends of these curves as compared to the probable errors of the points concerned leaves little doubt as to the reality of the correlation, and in general substantiates the earlier deductions based on the eastern stations alone.

Further investigations of possible astronomical causes have yielded little satisfaction for explanation of the phenomena on the basis of atmospheric or celestial sources, and tend to confirm the hypothesis of crustal movements to account for the observed changes in latitude. It is suggested that tidal movements in the asthenosphere may be partly responsible for the observed effects, but it must be emphasized that any geophysical explanation must be consistent with a true displacement of the vertical and not confused with land-tilts which could not displace the position of the astronomical zenith unless a distortion in the direction of gravity results.

Researches for detecting east and west coordinates of this effect have been undertaken by Professor M. F. Jordan of the University of Maine while on sabbatical

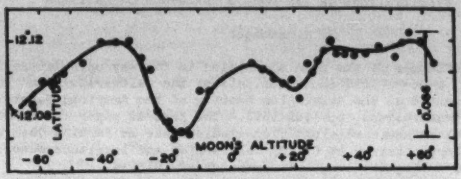

Fig. 2--Latitude-variation and moon's altitude from observations at Ukiah, 1909-11 (each point based on 500± observations)

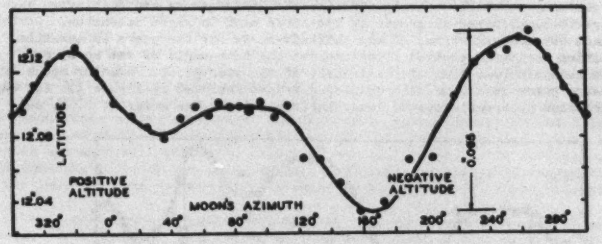

Fig. 3--Latitude-variation and moon's azimuth from observations at Ukiah, 1909-11 (each point based on 500± observations)

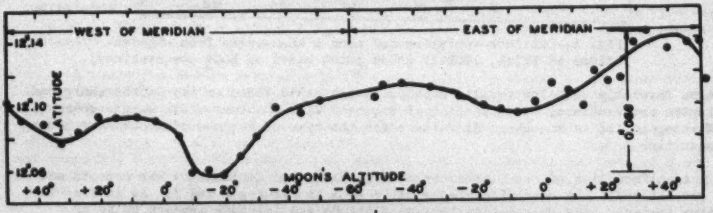

Fig. 4--Latitude-variation and moon's altitude west and east of meridian from observations at Ukiah, 1909-11

leave at the Perkins Observatory. A careful study of the time-observations recorded at Washington during the longitude-campaign of 1913-14 has rendered preliminary results indicating a meridional displacement eastward and westward, depending on the hour-angle of the moon at the time of observation of various star-groups.

An extensive study of a long series of time-observations obtained at Ottawa is now in progress by Professor Jordan at the Perkins Observatory. Acknowledgment is due Director R. M. Stewart of the Dominion Observatory for furnishing additional data, and to the National Academy of Sciences for a grant from the Gould Fund for assisting in furthering these investigations.

Perkins Observatory,
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THE ESTABLISHMENT ASTRONOMICALLY OF POINTS ON AN UNSURVEYED PROVINCIAL BOUNDARY

Noel J. Ogilvie

The establishment astronomically of points at intervals on a theoretical unsurveyed geodetic line is an unusual example of a specialized problem occurring in Canadian survey-practice. Where the line in question is long and does not form part of a parallel of latitude nor a meridian of longitude, the problem becomes mathematically complex requiring for its precise solution the application of advanced geodesy as well as the science of astronomy.

During the past season, the Geodetic Survey of Canada undertook the establishment astronomically of points at intervals on the unsurveyed section of the Ontario--Manitoba boundary between Island Lake and Hudson Bay. This 280-mile section of provincial boundary was defined by Act of Parliament in 1912 as a straight line joining the east end of Island Lake with the point where the 89th meridian of longitude intersects the south shore of Hudson Bay. The Island Lake terminal of this line had already been established on the ground and a precise determination made of its geographical position. The Hudson Bay terminal had not, however, been established nor the topographical features in that locality surveyed or mapped with the result that the latitude of this terminal was as yet unknown.

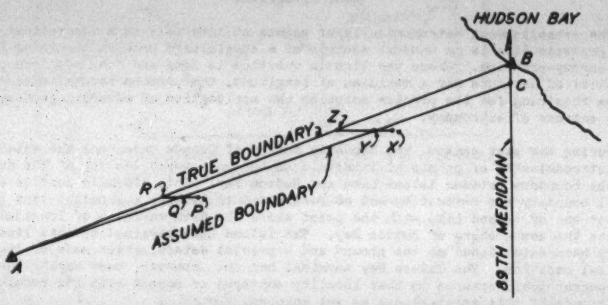
As a preliminary step to marking the boundary on the ground it was necessary to establish the Hudson Bay terminal according to the terms of its legal definition. A determination of the latitude at the same time was required in order to compute the length and terminal-azimuths of the theoretical line joining the two terminals. Topographical surveyors who were to carry out the demarcation of this line on the ground proposed to run a trial-line starting at Island Lake on the theoretical azimuth and to carry the line through as accurately as possible to Hudson Bay. By measuring the length of the perpendicular offset from the trial-line at the Hudson Bay coast to the boundary terminal-monument, it would then be possible to establish the true connecting-line.

The territory through which this line would pass had never been examined or explored with the result that little information was available regarding water-routes and general topography in the area. As an aid to the surveyors on the work of demarcation it was decided to photograph from aircraft a strip of country from Island Lake to Hudson Bay following as closely as possible the theoretical boundary. By plotting a provisional strip-map from these photographs the main water-routes would be shown with sufficient accuracy to guide the surveyor in planning his travel-routes and field-operations. An aerial photographic operation of this nature, however, along a theoretical line 280 miles in length over unmapped territory presented in itself serious difficulties. The navigation of aircraft has not as yet reached that stage of perfection where straight lines of this length may be successfully flown without checking the geographical position at intervals from topography recognizable below or without the aid of the radio beacon.

As the use of the radio beacon was not feasible it was decided to first establish two intermediate points astronomically on the theoretical line so chosen as to divide the line roughly into three equal parts. The program of work was finally enlarged to include the photographing from the air of the area in the neighborhood of these points, together with the laying down in the ground of sufficient control to properly orient and plot the local topography from the photographs. By this method the surveyor conducting the subsequent aerial photographic operation would have at his disposal at the end of each 100 miles of flight a fairly reliable map of the territory adjacent to the true line. Recognition of the terrain below would then permit of the correction of any serious deviation in flight from the desired course, and in this way help to ensure the success of the operation.

In a district where triangulation-control had previously been laid down from primary or secondary nets the problem would have been greatly simplified. In this particular area where the nearest geodetic triangulation-stations were hundreds of miles distant it was necessary to resort to astronomical methods. Due to errors in position-determination resulting from deviation of the plumb-line the points established by astronomical methods are not to be considered comparable in accuracy with

points established geodetically but should, however, be sufficiently accurate for the required purpose.



The above diagram will afford the reader a more comprehensive idea of the problem. The letter A denotes the fixed terminal at Island Lake already established on the ground, the latitude and longitude of which has been found to be 53° 44' 19".42 and 93° 39' 14".91, respectively. B represents the intersection of the 89th meridian of longitude with the coast-line of Hudson Bay, the boundary-terminal to be established. ARZB is the geodetic or shortest line on the Earth s surface joining A and B. R and Z are intermediate points to be established on the line.

In carrying out this undertaking the logical procedure would be to travel along the Hudson Bay coast, setting up and observing astronomically at intervals as one approached the desired location and finally the establishment, by a series of precise observations, of the exact point. From the geographical positions of the two terminals A and B, which would then be known, sufficient data would be available to place any desired number of intermediate points on the theoretical connecting-line.

As Royal Canadian Air Force aircraft were to be used for transportation in establishing intermediate points, consideration had to be given to the time when aircraft would be available. As the Air Force wished to complete the flying involved in this operation early in the season before it was feasible to proceed down the coast in boats to establish the terminal-point, it was necessary to change the order of procedure. Accordingly a point C was assumed as the Hudson Bay terminal in latitude 56° 48' 00".00 and longitude 89° 00' 00".00, the latitude being taken from the best available map. With these data, it was planned to establish intermediate points Q and Y on the assumed line and later in the season to locate the Hudson Bay terminal. By methods which will be explained later, the relative positions of the intermediate points Q and Y on the assumed line and R and Z on the true boundary are computed and represented on maps of the local areas.

In carrying out the actual survey-operations an advanced air-base was established at Gods Lake within 100 miles of the theoretical line. From the base at a known geographical position, a reconnaissance-flight was planned to search for a suitable lake on which to land in the neighborhood of the theoretical boundary. By carefully determining the ground-speed and wind at the elevation of flight it was possible, by methods of aerial navigation, to determine the approximate geographical position at any time during the flight. A lake was finally found, the geographical position of which was calculated to be on the line of the assumed boundary. Accordingly a landing was effected and preparation made for an observation for position. For the preliminary investigation, a modification of Sumner s nautical method of position-fixation was employed. To obtain the correct Greenwich time, a short-wave radio receiving-set was carried on which time-signals from the Washington Naval Observatory were received.

On returning to Gods Lake base from this reconnaissance-trip, the reduction of the observation showed the latitude and longitude of the observed station to be 54° 37' 50".00 and 92° 18' 25".00, respectively. In determining the distance of this

point from the assumed theoretical boundary an extensive computation was involved. The solution of this problem presented here, while reasonably simple, may not be the best method whereby the problem may be solved. Having given the geographical positions of the two terminals of the theoretical line, the first step consisted of the computation of the initial azimuth, the reverse-azimuth, and the length of the geodetic line joining A and C.

For the line AC, we have given for point A latitude = 53° 44' 19".42 and longitude = 93° 39' 14".91, and for point C latitude = 56° 48' 00.00 (assumed) and longitude = 89° 00' 00.00, from which we deduce azimuth of geodetic line A to C = 39° 03' 55".1, reversed azimuth C to A = 222° 53' 32.3, and log of intervening distance (meters) = 5.6542806.

Any geodetic line on the Earth's surface may be defined mathematically by the equation

$$N_A \cos L_A \sin Z_A = N_C \cos L_C \sin Z_C = \text{a constant}$$

where N_A is the normal to the ellipsoid of revolution intercepted by the minor axis, L_A is the latitude of the point A, and Z_A is the azimuth at A of the point C.

Applying this equation to the line AC, we have for the point A

Log N (53° 44', 19".00)	= 6.8056563
Log cos 53° 44' 19".42	= 9.7719315
Log sin 39° 03' 55".1	= 9.7994824
Sum	= 6.3770702

The number 6.3770702 is the logarithm of the constant of this particular geodetic line and its application will be demonstrated below. From the observation for position at the station P, the latitude was found to be 54° 37' 50.00. By substituting this value of the latitude in the equation of the geodetic line we may, by a number of steps, evaluate the longitude of a point on the assumed line corresponding to this value of the latitude. The longitude so deduced and the observed value will show the relative positions of the two points P and Q on the same parallel of latitude. For the point Q on the assumed line in latitude 54° 37' 50.00 we have

$$N_Q \cos L_Q \sin Z_Q = \text{a constant} = (6.3770702)$$

from which the azimuth at the point Q may be deduced.

sin Z_Q	= (6.3770702)/N_Q cos L_Q
log constant	= 6.3770702
log N (54° 37', 50")	= 6.8056781
log cos 54° 37' 50"	= 9.7825633
	6.5682414
log sin Z_Q	= 9.8088288
Z_Q	= 40° 05' 03".85

From the inverse solution already given we have Z_A = 39° 03' 55".11. The change in azimuth dZ = 1° 01' 08".74. The change in longitude dY in going along the line AC from A to Q is a function of the corresponding change in azimuth. This may be expressed mathematically as follows:

$$\tan 1/2\, dY = \tan 1/2\, dZ \cos 1/2\, dL / \sin 1/2\, (L_A + L_Q)$$

Applying this formula, we get

tan (dZ)/2	= 7.9490732
cos (dL)/2	= 9.9999868
	= 7.9490600
sin $(L_A + L_Q)/2$	= 9.9089710
tan (dY)/2	= 8.0400890
dY	= 1° 15' 24".00
Initial longitude at A	= 93° 39' 14.91
Longitude point Q	= 92° 23' 50".91

From a comparison of the longitude of P, the point observed, and Q, the point on the same parallel of latitude but on the assumed boundary-line, it is seen that the difference amounts to 5' 25".91 or a lineal distance of 290.71 chains. The length and direction of the perpendicular from P to the boundary is finally computed. Where the point of observation is relatively close to the theoretical boundary-line, the approximate azimuth may be said to equal $Z_Q \pm 90°$. While not strictly correct, this value will be sufficiently close for practical purposes. The length of the perpendicular equals PQ cos Z_Q. For this particular example

Z_Q	= 40° 05' 05".85
Subtract	= 90°
Azimuth perpendicular	= 310° 05'
log PQ in chains	= 2.4634600
log cos Z_Q	= 9.8837232
Sum	= 2.3471832
Length of perpendicular	= 222.42 chains

The preliminary reconnaissance-flight had, therefore, been successful in locating with a minimum expenditure of time and flying a distinctive topographical point within three miles of the assumed boundary.

The following day a camp was established on the same lake known locally to the Indians as Black Duck Lake. About a week was spent in triangulating to several prominent points and in observing on the stars for position from a point about one mile distant from the assumed line. John Ball's method adapted to the prismatic astrolabe was employed. In place of an astrolabe, however, a Wild transit was used with the telescope clamped at a fixed angle of 60°. The times of star-passages were recorded electrically on a portable chronograph. The time-signals were received from Washington by the vernier-clock method giving results accurate to 1/100 of a second of time.

Before returning to Gods Lake base, a series of aerial photographs was taken from an altitude of 5,000 feet, covering an area ten miles square around the point of observation. The topography shown on these photographs when plotted with reference to the observed station and the triangulation-control will show, with considerable accuracy, a fine cluster of five or six lakes hitherto unknown except to Indians and an occasional white trapper. These lakes range from six to fifteen miles in length and are separated from each other by only a few miles. On this map showing the local area, the assumed boundary and finally the true boundary may be shown and the position of either line identified from the ground or from the air by reference to the many arms and bays in this distinctive cluster of lakes.

The establishment of a second intermediate point on the assumed boundary was carried out in a similar manner. A point was finally located near Sturgeon Lake shown on most maps of northern Manitoba on the upper reaches of the Shamattawa River.

The remaining task of establishing the Hudson Bay terminal by precise methods was now undertaken. As it was not considered feasible to land aircraft on the shallow boulder-strewn tidal waters adjacent to this section of the Hudson Bay coast, the field party carrying out this undertaking made its way in canoes from the Nelson River, 170 miles along the coast, to locate the boundary-terminal at the point where the 89th meridian of longitude intersects the coast. On approaching the desired geographical position an approximate position-determination was made and a concrete pier erected on a suitable elevated point which ultimately proved to be one-half mile from the 89th meridian. A Hyde broken-telescope type astronomical instrument was used together with

other accessory instruments necessary to geodetic astronomical work of the greatest accuracy. An independent determination of longitude was made on each of four nights and about 30 pairs of stars observed for latitude.

In order to establish the actual terminal of the boundary-line, it was necessary to reduce these observations in the field. The small correction to the longitude due to personal equation and error in time of broadcasting radio signals had to be ignored. A small change in position of the terminal-monument due to this circumstance will be made when the line is marked on the ground. The results of the longitude determination showed the observation-pier to be in longitude 89° 00' 48".00, from which it was deduced that the 89th meridian lay 2,720.4 feet to the east. Measuring off this distance, the 89th meridian was established and then run northward a few hundred feet to intersect the coast-line. At the point of intersection a concrete monument was built extending into the ground five feet and a bronze tablet was imbedded in the upper surface. Over this monument a survey-beacon was erected twelve feet in height to aid in the future location of the more lasting monument below.

The precise latitude of the boundary terminal-monument deduced from the observation of 30 pairs of stars by Talcott's method was found to be 56° 50' 26".73, differing by 2' 26".73 of arc from 56° 48' 00".00, the assumed value. An inverse solution of the true line has been made giving the following results:

Z_A = 38° 40' 33".704
Z_B = 222° 30' 14".46
log distance AB (meters) = 5.6574769

A computation similar to that already shown in connection with the establishment of the intermediate point at Black Duck Lake gives the length and direction of the perpendicular from the point of observation at each of the intermediate stations to the true provincial boundary. The position of the true boundary may finally be shown in this manner on a map of each local area together with the astronomical station and the triangulation-control.

Geodetic Survey of Canada,
Ottawa, Canada

PROGRESS IN GEODETIC WORK DURING THE PAST YEAR

William Bowie

General statement--Practically all of the field-work in geodesy in the United States is executed by the United States Coast and Geodetic Survey. That organization is charged by law with extending triangulation- and leveling-nets over the country, making gravity-surveys in the United States and its outlying areas, and observing the variations of latitude at Ukiah, California, and Gaithersburg, Maryland.

In the office of the Coast and Geodetic Survey in Washington, D. C., computations and adjustments of the observations made in the field are carried on; interpretations of the data are made and research in certain geophysical problems are conducted in which the geodetic data are used. The development of instruments for making the field-observations is also a part of the normal duties of the office.

Expanded geodetic program--For several years prior to the present fiscal year the funds available annually for the field geodetic work were $98,600. Under it the progress made in extending the geodetic surveys over the country was quite slow. Many statements of opinion had been expressed by engineering and scientific associations and societies and by individuals that the geodetic surveys should be expedited in the interests of science, engineering, and industry. This tended to create a feeling on the part of Government officials that this work was of sufficient importance to justify larger annual appropriations. President Hoover, after careful consideration of the subject, added $200,000 to the appropriation of the Coast and Geodetic Survey for geodetic work for the fiscal year 1930. Already $40,000 additional for geodetic work had been recommended to the Director of the Bureau of the Budget by Secretary Lamont, head of the Department of Commerce. This additional $240,000 was used largely for field-

expenses, while a portion of it was used to employ several additional engineers for the permanent staff. Provision was made in the appropriation bill that $30,000 of the increase should be made available for the employment of personnel in the office at Washington to be used in computing and adjusting field-data and in preparing the results for publication. To the geodetic item was added $2,500 to make it possible to recondition and open the variation-of-latitude station at Gaithersburg, Maryland.

At present the appropriation for geodetic field-expenses, including the $30,000 available for additional personnel in the Washington office, is $326,000. The increase, which is a very substantial one, went into effect July 1, 1930, and already Congress has made an appropriation of a like amount for the fiscal year beginning July 1, 1931.

For several years past an effort has been made to complete the triangulation-net of the eastern half of the country to such an extent that a readjustment might be made. A readjustment of the triangulation of the western half of the country has already been made with highly satisfactory results. During the present fiscal year, triangulation has been executed along the following arcs: (1) Along 42nd parallel from Columbus, Nebraska, to a point just south of Chicago, Illinois; (2) from Cairo, Illinois, through Kentucky to Nashville, Tennessee; (3) from Cairo, Illinois, to Poplar Bluff, Missouri; (4) from Cairo, Illinois, to Belleville, Illinois, connecting with transcontinental arc; (5) along 94th meridian from Fort Smith, Arkansas, southward through Louisiana to the Gulf Coast in the vicinity of Port Arthur, Texas; (6) from Shreveport, Louisiana, eastward to Forest, Mississippi; (7) from Mobile, Alabama, westward to the vicinity of Galveston, Texas; and (8) from La Crosse, Wisconsin, eastward to Fond du Lac, Wisconsin.

The total of these arcs of first-order triangulation is approximately 1,950 miles. The only work that remains to be done, to provide for the eastern adjustment, is the arc extending from the vicinity of Galveston westward along the coast to Corpus Christi, Texas. This arc, which is 250 miles in length, should be completed by July 1, 1931.

The Corps of Engineers, United States Army, has requested the Coast and Geodetic Survey to extend an arc of first-order triangulation along the Mississippi River from the vicinity of Cairo, Illinois, northward to the vicinity of St. Paul, Minnesota. This arc will supplement the triangulation-net of the country and will provide connections at frequent intervals with the stations of existing triangulation along the Mississippi River. A transfer of funds from the War Department to the Coast and Geodetic Survey was made in order to pay part of the expenses of the work. This work was started early in April and should be completed within the next five months. The arc is approximately 650 miles in length.

During the past year 15 first-order bases for controlling the lengths of triangle-sides have been measured. They lie along the arcs of triangulation which are mentioned above. The total length of these bases is 108 miles and the average probable error of the base-measurements is one part in 3,000,000. There are 39 miles of bases yet to be measured along the arc from Mobile, Alabama, to Corpus Christi, Texas, to complete the data needed for the adjustment of the eastern half of the triangulation-net. It is expected that these remaining bases will be completed late in June or early in July 1931.

Observations have been made in the field to determine the astronomical azimuths of certain lines of the triangulation-net. At most of these stations, azimuth-determinations were made by the triangulation-parties as the triangulation-work progressed. However, at a few stations the longitude-and-latitude parties made the azimuth-observations.

Two parties were operating during the early part of the year in the determination of astronomical latitudes and longitudes at triangulation-stations and during the latter part of the year one such party remained in the field. The observations of longitudes are for the purpose of determining the deflections of the vertical in the prime vertical at certain triangulation-stations at which are also determined the astronomical azimuths. After a knowledge of the deflection of the vertical is available, corrections can be made for the tilting due to this cause of the horizontal axis of the

theodolite used in making azimuth-observations on Polaris. After such corrections are applied, azimuths can be obtained which are referred to the meridians of the spheroid, such azimuths being used in adjusting the arcs of triangulation to their true directions.

The astronomical latitude was determined at each of the longitude-stations in order to obtain the deflection of the vertical in the meridian. These deflections are of value in determining the figure of the Earth and for certain other scientific purposes.

Occasionally the triangulation-parties have determined astronomical azimuths at stations other than those at which astronomical longitudes were determined. These intermediate azimuths, as they are called, furnish a fair value for the deflections of the vertical in the prime vertical.

Reconnaissance for triangulation--The selection of triangulation-stations and the routes for triangulation, called reconnaissance, has been carried on as rapidly during 1930 as was necessary to furnish data for the triangulation-parties. However, at the end of the year the triangulation-parties had completed the work along practically all of the arcs laid out. During the coming year an effort will be made to do a large amount of reconnaissance, probably 4,000 or 5,000 miles of arcs. This will provide for the triangulation-parties for the calendar year 1931 and for the first part of 1932.

No attempt has been made to run the arcs of triangulation directly north and south or east and west. They are located along those routes over which there is easy transportation and so far as practicable are made to cut in half any large areas surrounded by existing arcs.

The general plan for the triangulation is to have first-order arcs spaced at intervals of about 100 miles with certain cross-arcs for adjustment-purposes, and to have the intermediate areas cut across by arcs of second-order triangulation. The average closing-error of a triangle in the first-order work is about one second, while for the second-order work it will be less than three seconds--probably about two seconds. These latter accuracies are sufficient for all except the most exacting scientific and engineering uses to which the triangulation will be put.

Triangulation in regions of seismic activity--Congress continues to make available $10,000 per year for executing geodetic work in regions of seismic activity. This item was first included in the appropriation of the Coast and Geodetic Survey in 1923.

During the past year the triangulation executed under this item consisted of a short arc of first-order triangulation extending eastward from the vicinity of Monterey Bay, California. The first-order arc was connected with existing first-order stations of the California Coast Arc. Intermediate stations were placed at frequent intervals, averaging a mile or two apart, and these were tied into the first-order arc. The object of this work is to furnish the means for determining the extent of Earth movements should there be an earthquake near this triangulation. The arc crosses several fault-zones and the supplemental stations are placed closer together near the faults than in intermediate areas.

In addition to this arc, some work was done in completing a similar arc of triangulation which lies to the eastward of Point Reyes, California.

Connection between triangulation of Mexico and the United States--As is well known, the geodetic organizations of the United States, Canada, and Mexico have adopted the same spheroid for their work and are using the same initial station, Meades Ranch in Kansas, for the triangulation-system of the whole continent.

The triangulation of Canada and the United States is connected at a number of points along the International Boundary and there are also connections between the triangulation of Mexico and the United States in the vicinity of the 98th meridian, 117th meridian, and at El Paso, Texas. The last-mentioned connection was made by officials of the Coast and Geodetic Survey and the Geographic Service of Mexico during the winter of 1930-31.

It is of the greatest scientific interest that there is a connected system of triangulation for the whole continent. Already triangulation has been extended along the coast of British Columbia and through southeast Alaska to Skagway, and the Canadian Government has carried the triangulation quite well to the northward of the International Boundary. Mexico has triangulation extending southward from the Rio Grande to the Pacific Ocean along the 98th meridian, and has several other arcs. With this connected scheme, it is possible to determine a figure of the Earth, which should be very much more exact than any other that has been derived. It is hoped that a new figure of the Earth may be determined from the triangulation of North America in the very near future.

New length measurement for Professor Michelson--Upon the request of Professor Michelson, the Director of the United States Coast and Geodetic Survey authorized Clem L. Garner, Assistant Chief of the Division of Geodesy, to measure the length of the tube, which is a part of the apparatus designed by Dr. Michelson to redetermine the velocity of light. This tube is approximately 1,594 meters in length. Mr. Garner used four 50-meter invar base-tapes in making the measurements and secured an accuracy, between two end-monuments, of approximately one part in a million of the length. The probable error of the mean of the measurements is very much smaller than one part in a million. It was impracticable for Mr. Garner to make a connection between his monuments and the mirrors of the Michelson apparatus but it will be a simple matter to offset the measured distance to the line between the mirrors.

The standardization of the lengths of tapes used in these measurements was done at the Bureau of Standards at Washington, D. C. The computations involved in this measurement have not been completed at the time this paper is being written but the data will be available very soon.

Computation and adjustment of the triangulation-net of the eastern part of the United States--The adjustment of the triangulation-net covering the western half of the United States, which was completed a few years ago, proved so very satisfactory that it was decided to make an adjustment by the same methods of the triangulation lying to the east of the 98th meridian.

Prior to the present year there were 12,000 miles of arcs of triangulation in the eastern part of the country executed by the Coast and Geodetic Survey and by the United States Lake Survey. In addition, there were 650 miles of arcs lying in Canada, which had been connected with the triangulation of this country.

It was found that in order to strengthen the existing network sufficiently to make the adjustment effective, some new arcs would have to be executed. These arcs, 2,200 miles in length, mentioned in the early part of this paper, have been nearly completed. All that remains to be done is a short arc lying along the Gulf Coast to the eastward of Corpus Christi, Texas. This has been a tremendous piece of work, for no country has previously executed so many miles of first-order triangulation in one year. The necessary base-measurements will be completed by July 1, 1931, and already the Laplace azimuths have been practically completed. The triangulation of the eastern half of the United States and that of Canada is combined in what we call the Eastern Triangulation-Net Adjustment.

At the time of writing this report, there are from fifteen to twenty mathematicians and computers engaged upon the adjustment of the eastern net. The net has 32 junction-points, with a set of equations required for each one, and there are 60 sections of triangulation between junction-points. The triangulation-stations along the 98th meridian to which the eastern arcs are connected will be held fixed in the positions derived by the western adjustment. It is believed that the adjustment of the net in two sections will give practically as satisfactory and as strong results for the whole country as if the net had been adjusted as a single unit.

It is hoped that the most probable values of the geographic positions of the junction-point stations as determined by the adjustment will be available in the late fall of 1931. When these data are obtained it will be necessary to make adjustments between the junction-points of the many sections of the net but this latter work can go along rather rapidly as compared with the preliminary adjustment of the net.

Adjustment of combined first-order level-nets of the United States and Canada--In previous years it has been reported to the Section of Geodesy of the American Geophysical Union that an adjustment of the combined first-order level-nets of the United States and Canada had been completed in the office of the United States Coast and Geodetic Survey at Washington, D. C. In that net were involved 66,000 miles of leveling and 26 tidal stations at which mean sea-level had been accurately determined. The adjustment of the level-net indicated clearly that there was a slope upward toward the north of the sea-level surface and that the average elevation of mean sea-level on the Pacific Coast is approximately two feet higher than the average mean sea-level on the Atlantic and Gulf Coasts.

Conferences were held between officials of the Geodetic Survey of Canada and the United States Coast and Geodetic Survey for the purpose of discussing the results of the level-net adjustment and arriving at an understanding as to what elevations should be used for the bench-marks along the International Boundary. The results of these conferences is that the United States is holding fixed the elevations of the junction-points of the leveling of the United States and the elevations derived from the adjustment for the bench-marks along the International Boundary. Already much work has been done at the Washington office towards fitting in the sections of the leveling between the fixed elevations of the junction-points.

The leveling-data for the state of New Jersey have been published in pamphlet form. It is hoped that within the next few years the leveling data for several other states will appear in published form.

The Canadian officials decided that it would be impracticable for them to adopt the elevations furnished by the General Level-Net Adjustment of the bench-marks at the International Boundary. Canada, only a few years ago, made a general adjustment of its leveling-net and the results of that adjustment have been published. There are a number of large engineering works being based upon the elevations furnished by that adjustment. Under these circumstances, it would be impracticable to immediately change the elevations of the Canadian net. However, Canada is extending its leveling-net rather rapidly and perhaps a new adjustment of the leveling-lines in that country will have to be made in the near future. At such time as an adjustment of that kind is made in Canada, it may be possible that the boundary-elevations as furnished by what may be called the North American level-net adjustment can be held.

Variation of latitude--Observations have been continued throughout the year at the variation-of-latitude station at Ukiah, California, which has been in operation since 1900. Until the World War that station and the one at Gaithersburg, Maryland, were supported by funds of the old International Geodetic Association. Since the War, the Coast and Geodetic Survey, through appropriations made by Congress, has financed the work at Ukiah. Congress, in its appropriation for the fiscal year 1931, provided $2,500 for the Gaithersburg station. This money has been used for reconditioning the buildings and grounds at Gaithersburg and this station will very shortly be in good condition. It is expected that the observations at Gaithersburg will be resumed about July 1, 1931.

The Coast and Geodetic Survey in carrying on the variation-of-latitude work is cooperating with the Joint Committee on International Variation of Latitude which is composed of members of the International Astronomical Union and of the International Geodetic Association of the International Union of Geodesy and Geophysics. The Chairman of that Committee is Professor H. Kimura, Director of the Observatory, Mizusawa, Japan.

Isostatic reduction of deflection-of-the-vertical stations in the United States--Owing to the great amount of work involved in the computation and adjustment of the triangulation- and leveling-nets of the country during 1930, not very much effort could be given to the isostatic reduction of deflection-of-the-vertical stations. However, such reductions were made for six stations in or near the Black Hills, South Dakota. This is a region that is particularly interesting to the geodesist for the gravity-anomalies in the vicinity have positive values and are comparatively large. It was desired to learn whether the deflections of the vertical showed the same characteristics, in so far as abnormal attractions were concerned, as are indicated by the gravity-anomalies. No intensive study of the results of the isostatic reduction of the stations in question has been completed at the time of writing this report.

Determinations of gravity in the Bahama Islands--Prior to the last annual meeting of the American Geophysical Union, Joseph F. Lushene, an engineer of the United States Coast and Geodetic Survey, had determined the value of gravity at six stations in the western Bahamas. This work was done as a part of an International scientific expedition sent out under the auspices of the Summer School of Geology of Princeton University. The stations extended 110 miles north and south and 120 miles east and west with a fairly uniform distribution. The gravity-anomalies for these stations were all negative, but not very large. The average anomaly was minus 0.021 dyne, and the maximum anomaly was 0.035 dyne. These comparatively small anomalies indicate very clearly that the block of the Earth's crust under that portion of the Bahamas near the stations is in approximate isostatic equilibrium. The fact that the anomalies are negative is a clear indication that the Islands are not under-laid by igneous rock close to the surface.

A statement was prepared at the office of the Coast and Geodetic Survey and furnished to Professor Field of Princeton to be included in his report on the results of the expedition.

Improvements in instruments--Slight changes have been made in the 9-inch Parkhurst theodolite during the year, which makes that instrument most satisfactory in its operation in the field. As is well known, this is an instrument designed at the office of the United States Coast and Geodetic Survey by D. L. Parkhurst, Chief of the Instrument Division. It has been tested in the field for more than a year and the engineers using it report that it is rapid in operation, accurate in its results, and very convenient to handle. This is the standard first-order theodolite of the Coast and Geodetic Survey. Other instruments like it have been manufactured and it is expected that after circles have been graduated for them they will be sent to the field.

A new 6 1/2-inch direction-theodolite has been constructed at the office of the Coast and Geodetic Survey. This instrument was also designed by Mr. Parkhurst and is very similar to the 9-inch Parkhurst theodolite. It will be the standard theodolite of the Coast and Geodetic Survey for second- and third-order triangulation. It has been given preliminary tests in Washington, which indicate that it is very satisfactory and at the time this report is being written it is in the field receiving a more severe test.

Improvements have been made in the graduation and structure of the first-order level-rods. The graduations of the invar strip used in level-readings are so nearly perfect that a rod does not now have to be used at a turning-point for both the forward and backward sights. The perfection of the graduation of these rods enables the observer to adopt methods of operation in the field which result in a substantial increase in the rapidity with which the work can be done.

Investigations have been made with a view to finding the best paint and shellac with which to mark the graduation-numbers, etc., on the metal and wooden parts of the rod. Improvements in this regard have been made and the rod can stand hard usage in the field much more effectively than was formerly the case.

A new way of preparing the foot of the rod has been adopted, which it is believed is an improvement over the old method.

During the year the Coast and Geodetic Survey purchased from the Geodetic Survey of Canada seven precise-levels of the Coast and Geodetic Survey type. The latter organization has adopted the Zeiss first-order level as its standard equipment and, therefore, had no further use for the other type of instrument. The Coast and Geodetic Survey was glad to get these Canadian levels, for our engineers are thoroughly satisfied with this type of instrument, both for accuracy and rapidity of operation.

Improvement in gravity-apparatus and methods--The Coast and Geodetic Survey has for many years been making gravity-observations in the field by means of quarter-meter pendulums. With this apparatus results of a high degree of accuracy can be obtained but the time consumed at a single station is several days. It has been felt for some time that there should be a careful study of the pendulum and the methods of its use, with the idea of making improvements which would enable the observer to secure a value of gravity of high accuracy in a short interval of time.

E. J. Brown, an engineer of the Coast and Geodetic Survey, has been making researches in the gravity-problem for the past year or more. Under his direction a new case has been made for the pendulums, which it is believed will make for ease of operation and greater accuracy in results. The case is supported at points, which are almost exactly in the horisontal plane, through the head of the pendulum. By having the supports here instead of under the case, it is believed that the effects of flexure will be somewhat reduced. Another feature is that all the necessary manipulating of the pendulums within the case is done by means of a single shaft which lifts the pendulum from its support, clamps it, starts it, etc. There is thus not so much chance of the case leaking as formerly. Formerly, before beginning observations, the air was exhausted from the case to about 60 mm of mercury pressure. It is believed that a lower pressure can be used to advantage in the new case.

Mr. Brown has been working with photoelectric cells and other apparatus with a view to perfecting a method by which the radio time-signals received from the Naval Observatory may be compared directly with the oscillations of the pendulum. It is believed that the method is satisfactory but definite tests cannot be obtained until field-work in gravity is done during the coming summer.

If the new method of comparing the time-signals with the oscillation of the pendulum is successful, additional time-signals from the Naval Observatory would be of considerable help. At least two new sets of signals would be desirable, one about 8 o clock in the forenoon and the other about 4 or 5 o clock in the afternoon. These new time-signals, together with the 10:00 p.m., 3 a.m., and noon signals which are now sent, would give five intervals between time-signals during each day, and would greatly expedite the observations.

The Director of the Coast and Geodetic Survey has indicated his intention of having an engineer of the Bureau make a redetermination of the difference in the value of gravity between the fundamental station at Potsdam, Germany, and Washington, D. C. This determination is of importance because there are now three values for the difference between Potsdam and Washington, determined by Putnam, Miller, and Meinesz. The three resulting values for Washington are, respectively, 980,112, 980,117, and 980,121. The range here is much larger than the probable error of the determination of the difference in gravity between Potsdam and Washington. At the Bureau of Standards, Dr. Heyl is now determining the absolute value of gravity and it is very desirable that his value be compared with that at Potsdam by the relative method. There are, therefore, two reasons why we should have a new determination of this difference, namely, to permit a comparison of the Heyl and the Potsdam values of absolute gravity, and to furnish a more reliable value for the base-station for relative gravity in the United States.

Miscellaneous investigations--A number of investigations of more or less importance have been made in the office in Washington involving certain phases of geodesy, physics of the Earth, map-projections, etc. So far as practicable, the personnel of the Division of Geodesy of the United States Coast and Geodetic Survey makes an effort to utilise the field-data and office-computations, and office-adjustments in interpreting the processes which are active within the Earth. From time to time papers have been prepared and published dealing with the studies involved.

Physics-of-the-Earth Bulletin of the National Research Council--One of the leading events in geodesy during the past year was the preparation of Volume II of the Bulletin on Physics of the Earth of the National Research Council. This volume contains sixteen chapters on ocean- and earth-tides, gravity, deflections of the vertical, isostasy, figure of the Earth, geodetic instruments, variation of latitude, etc. These are all important branches of the wide field of geodetic science. These chapters were prepared by scientific workers of prominence in their special fields, except for one paper, which was a reprint of an important paper of the late Clarence E. Dutton, entitled "On some of the greater problems of physical geology." It was during the presentation of that paper that Dutton coined the word "isostasy."

The papers in the volume under consideration are designed to give a brief description of each of the subjects treated and to outline problems connected with the several subjects. The papers are written in a semi-technical way in order that they may appeal to the readers who are not specially versed in the science of geodesy.

Publications of the Coast and Geodetic Survey--Among the important geodetic publications issued by the Coast and Geodetic Survey during the year should be mentioned the following:

Special Pub. No. 164, First-order triangulation in southeast Alaska.

Special Pub. No. 166, Geodetic operations in the United States, January 1, 1927 to December 31, 1929 (Report to the Section of Geodesy of the International Union of Geodesy and Geophysics).

Special Pub. No. 169, First-order leveling in Alaska.

Special Pub. No. 171, World longitude-determinations by the United States Coast and Geodetic Survey in 1926.

Special Pub. No. 172, First-order leveling in New Jersey.

Conclusion--The work in geodesy outside of that done by the United States Coast and Geodetic Survey consisted in the execution of triangulation and leveling of a high order in a few cities of the country. There is developing a widespread sentiment among city engineers that first-order control-surveys are of great benefit to them in their surveying and mapping work. Horizontal control-surveys in the form of triangulation and traverse are essential for the proper location of the corners of city lots. It is believed that the use of first-order triangulation and leveling in city surveying will spread rapidly in the years to come.

The various branches of the Corps of Engineers, United States Army, and the United States Geological Survey engage on certain geodetic work of third-order for their immediate needs in connection with mapping and engineering work. Where practicable, the engineers of those two organizations connect their triangulation and leveling with existing first- or second-order control-stations of the United States Coast and Geodetic Survey.

U. S. Coast and Geodetic Survey,
Washington, D. C.

AMERICAN GEOPHYSICAL UNION

Twelfth Annual Meeting

REPORTS AND PAPERS

S E C T I O N O F S E I S M O L O G Y

Washington, D. C.
April 30, 1931

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VELOCITY OF EXPLOSION-GENERATED LONGITUDINAL WAVES IN A NEPHELINE SYENITE

L. Don Leet and Maurice Ewing

The determination of velocities is one of the fundamental objectives of seismological investigations on any scale. Knowledge of the speeds with which energy is propagated as elastic waves in the materials of the Earth is basic to all interpretations of seismological data. In view of this, it is surprising how little seems to have been done in the way of making rigorous determinations of those speeds.

Values for velocities have been computed on the basis of laboratory measurements, at ordinary temperatures and varying pressures, of the elastic constants and densities of many rock-types. Kusakabe (4), Daly (2), and others, however, have warned against possible error in assuming identity between the cubic compressibility of a rock as measured in the laboratory and that which is effective in the propagation of seismic waves. Both the variation of pressure and the period of time during which the pressure is changed are of different orders of magnitude in the two cases. Daly (3) has recently summarized four different kinds of experimental evidence which suggest that the seismically effective compressibility of a rock is of the order of one-fifth less than its compressibility as determined by the high-pressure laboratory method. He further points out that additional specially designed experiments to test this idea are urgently needed.

This difference between the static and the dynamic constants would be predicted for rocks which exhibit elastic hysteresis, since that signifies departure from strict obedience of Hooke's Law. Conversely, statically determined constants for specimens which do not exhibit hysteresis might be expected to agree reasonably well with those measured dynamically.

Adams and Coker (1) have reported work on a specimen which is in the latter class. In the course of their work, they used one specimen of nepheline syenite from Corporation Quarry, Montreal, Canada. They describe this syenite as "composed chiefly of light-colored 'salic' constituents of which feldspar is by far the most abundant. This is chiefly orthoclase, but this mineral is much intergrown with plagioclase, which is also present in not inconsiderable amount. Associated with the feldspar is nepheline in rather small amount. . . . The dark 'femic' constituents are represented chiefly by a greenish-brown alkali horn-blende. . ." In marked contrast to specimens of granite, marble, limestone, etc., the syenite showed practically no hysteresis for longitudinal strains.

The constants were: Poisson's Radio, σ, the ratio of lateral extension per unit of length to longitudinal compression, 0.2560; modulus of cubic compression, 4.290×10^{11} c.g.s.; Young's Modulus, E, the quotient of the longitudinal stress by the longitudinal compression, 6.29×10^{11} c.g.s. Using these values for σ and E, with a value of $\rho = 2.60$ for an average syenite density, in the formula (see reference 5)

$$V^2 = (E/\rho)[(1 - \sigma)/(1 + \sigma)(1 - 2\sigma)]$$

gives a value of 5.419 km/sec (17,780 ft/sec) for the velocity of longitudinal vibrations.

Theory of field-measurements of velocity--The only accurate method of determining velocities in the field is the method of profiles. A profile is established by firing a series of explosive charges at various points along a straight line which terminates at a seismograph. Or, amounting to the same thing, records may be taken at various points along a straight line which terminates at the point at which charges of explosive are repeatedly fired. The quantities which are measured are the distance, x, from each station along the profile to the origin, and the time, t, which is required for the first disturbance (the longitudinal waves), or any other phase being studied, to travel that distance. These data are used in plotting a time-distance graph.

The observation of a single point, or two or three widely scattered points, on such a graph is, of course, entirely inadequate to determine its true form. If the

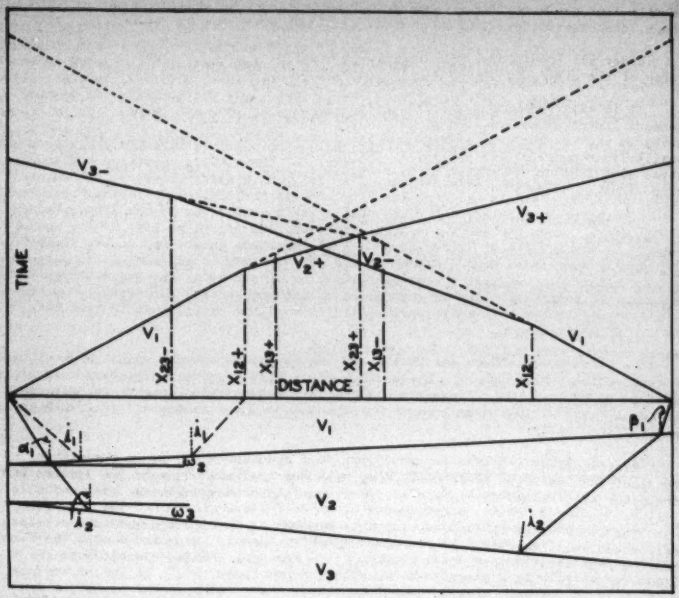
V3-
V3+
V2+
V2-
TIME
V1
V1
X23-
X12+
X13+
DISTANCE
X23+
X13-
X12-
V1
P1
i1
i1
g1
ω2
V2
ω3
i2
i2
V3

Fig. 1

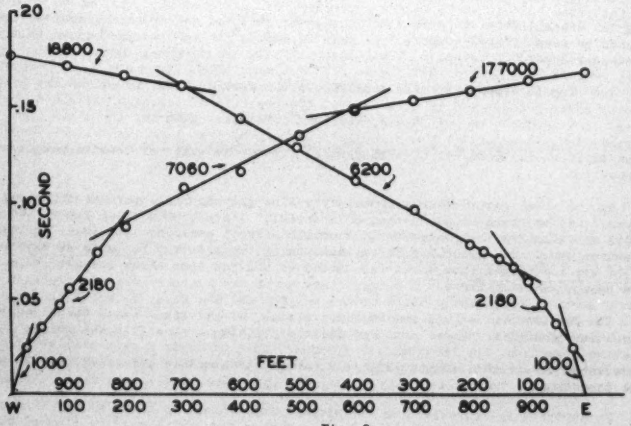
20
.15
.10
.05
SECOND
18800
177000
7060
6200
2180
2180
1000
1000
FEET
900 800 700 600 500 400 300 200 100
W 100 200 300 400 500 600 700 800 900 E

Fig. 2

profile is a few miles long, there should be scores of points observed. If it is short, the observations should be closely and uniformly spaced.

Under all conditions, it is essential to have at least two profiles, one the reverse of the other, to obtain a unique solution for the velocity desired.

It is well known that the time-distance graph for waves travelling in a homogeneous isotropic medium is a straight line whose slope indicates the velocity of the waves in that medium. If this medium rests in a horizontal contact on another layer similarly homogeneous and isotropic, but with such constants that it transmits the waves with greater velocity, the time-distance graph will show a second branch whose slope indicates the velocity of waves in the lower medium.

If, however, the plane of contact between these media is not horizontal though it remains undistorted, in all directions except that of the strike of the contact, the second branch of the time-distance graph will not indicate the true velocity in the second layer. For profiles directed up the dip of the contact, the slope of this second branch will indicate a velocity greater than the true velocity, and for those directed down the dip, less. These have been called apparent velocities.

A further complication is introduced if these two layers are underlain by a third whose contact with the second is also dipping.

Both cases have been treated by Oswald v. Schmidt (6, 7). A diagram illustrating his terminology is included here (Figure 1) to clarify the numerical computations which follow. Parallel horizontal layers on top of the V_1-layer do not affect these results.

Field-determination of velocity--Figure 2 shows the time-distance graph for the two profiles used in this determination, together with a profile of the surface and the datum plane to which irregularities in topography were corrected.

The 1,000 ft/sec surface-velocity represented by lines running from the origins was determined independently. Shots at fixed distances were repeated with hole depths ranging from 1 to 10 feet and the time-differences thus obtained showed a velocity of 1,000 ft/sec in the top soil.

The slope of the second line on each profile indicates a velocity of 2,180 ft/sec. The fact that this is the same for both profiles indicates that the top surface of the material transmitting vibrations with that velocity was practically parallel to the assumed surface. This material, as later found by drilling, was an unconsolidated, water-soaked sand.

The slope of the third line indicates a velocity of 7,060 ft/sec on the profile running eastward, assumed in this case as the positive direction of x, and 6,200 ft/sec in a westward or negative direction. This means that the third stratum, transmitting vibrations with a velocity somewhere between these two values, had its upper surface inclined, with a component of dip to the west relative to the assumed datum-plane.

By the application of the formulas for a single sloping-layer, accompanying Figure 1, it was found that the layer in question had a component of dip to the west of 1°3 and that the true velocity of vibrations in it was 6,600 ft/sec. Particular attention should be directed to this evidence of the effect which even an extremely slight dip has upon apparent velocities. The drilling operations revealed this layer as a brown, water-soaked clay.

The fourth, and last, lines of the profiles have slopes which indicate apparent velocities of 17,700 ft/sec in the positive direction of x, and 18,800 ft/sec in the negative direction, for the supposed syenite. This presents a case similar to that represented diagrammatically in Figure 1, where the inclined interfaces dip in opposite directions.

By applying the formulas for two sloping interfaces, as shown below, it was found that the surface of the syenite was dipping toward the east along the line of the

profiles at an angle of 3°55, and that the true velocity in it was 18,130 ft/sec, or 5.526 km/sec.

Numerical computations--For V_1 = 2,180 ft/sec, V_{2+} = 7,060 ft/sec, V_{2-} = 6,200 ft/sec, V_{3+} = 17,700 ft/sec, and V_{3-} = 18,800 ft/sec

(1) $\sin (i_1 - \omega_2) = V_1/V_{2+} = 2,180/7,060 = 0.3088$, therefore $(i_1 - \omega_2) = 18°0$

(2) $\sin (i_1 + \omega_2) = V_1/V_{2-} = 2,180/6,200 = 0.3516$, therefore $(i_1 + \omega_2) = 20°6$

whence $i_1 = 19°3$ and $\omega_2 = 1°3$.

(3) $\sin i_1 = V_1/V_2$, therefore $V_2 = V_1/\sin i_1 = 2,180/0.3305$

whence $V_2 = 6,600$.

(4) $\sin (\alpha_1 + \omega_2) = V_1/V_{3-} = 2,180/18,800 = 0.1159$, therefore $\alpha_1 + \omega_2 = 6°7$

whence $\alpha_1 = 5°4$.

(5) $\sin (\beta_1 - \omega_2) = V_1/V_{2+} = 2,180/17,700 = 0.1232$, therefore $\beta_1 - \omega_2 = 7°1$

whence $\beta_1 = 8°4$.

(6) $\sin \beta_1/\sin i_1 = 0.1461/0.3305 = 0.4421 = \sin(i_2 - \omega_{32})$, therefore $i_2 - \omega_{32} = 26°2$

(7) $\sin \alpha_1/\sin i_1 = 0.0941/0.3305 = 0.2847 = \sin(i_2 + \omega_{32})$, therefore $i_2 + \omega_{32} = 16°5$

whence $i_2 = 21°35$ and $\omega_{32} = -4°85$.

(8) $\omega_{32} + \omega_2 = -4°85 + 1°3 = -3°55 = \omega_3$

(9) $V_2/\sin i_2 = 6,600/0.3641 = 18,130 = V_3$

Conclusion--This work was done in Saline County, Arkansas, Township 2 South, Range 15 West, Section 30. The syenite outcrops a mile west of this point, and that is the nearest place from which data concerning its composition are available.

A well was drilled on the profile-line subsequent to these velocity-determinations, but the only evidence available from it is that the igneous rock encountered, in small chips examined by the unaided eye, appears to be similar to that of the outcrops, locally known as "blue granite." Analyses of specimens from the vicinity of the outcrop have been published (8). They show a composition of roughly 75 per cent potash-soda feldspar, 10-20 per cent nephelite, and the balance ferro-magnesian pyroxenes and amphiboles. There was, of course, no free quartz.

The fact that the dynamically determined velocity is only 2 per cent greater than the statically determined value for these two syenites, for which there is strong presumptive evidence of essentially similar composition, is to be expected, as indicated above, from the fact that Adams and Coker report no measurable hysteresis in the laboratory specimen.

An indication of the accuracy of the above results is given by the fact that the data were used in predicting a depth to the syenite, which was found by subsequent drilling to be within 2.5 feet of the true value, in a depth of 220 feet.

The authors wish to acknowledge their indebtedness to the Geophysical Exploration Company of Washington, D. C., who, through their vice-president, H. Gordon Taylor, have made possible the publication here of field-data obtained for it.

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GEODETIC WORK LAYS THE BASIS FOR STUDY OF EARTH-MOVEMENTS

William Bowie

The expanded program for the geodetic work of the United States is of especial importance to seismologists. As is well known, the triangulation and leveling involved in this geodetic program are designed to furnish very accurate geographic positions and elevations. After an earthquake has occurred near an arc of triangulation or line of levels, the field-observations can be repeated and the extent of the horizontal or vertical movements of the Earth's surface can be determined. It is especially important that we should learn the maximum distance, at right-angles to the active fault, to which the movements extend.

During the present fiscal year, that is, the one which began July 1, 1930, the United States Coast and Geodetic Survey will complete about 2,400 miles of arcs of first-order triangulation and between 5,000 and 6,000 miles of first-order leveling. If the present rate of annual appropriation is maintained, it is expected that the first- and second-order control surveys of the country will be finished within the next twelve years.

The arcs of triangulation and lines of levels of the first-order are spaced approximately 100 miles apart with cross arcs and lines required for purposes of adjustment. The intermediate areas will be crossed by second-order arcs of triangulation and lines of levels so that eventually there will be no place in the country more than about 25 miles from a first- or second-order triangulation-station or leveling bench-mark.

The second-order triangulation and leveling are very strong. They are slightly less accurate than is the first-order work but since the second-order arcs of triangulation and lines of leveling do not have to be extended for such long distances, the accuracy with which the observations are made in the field does not have to be quite as great as that of first-order work.

When this network of arcs of triangulation and lines of levels have been completed, it is reasonably certain that the epicenter of any major earthquake in this country will not be far from an arc of triangulation or a line of levels.

During the period since the last meeting of this Section, the Coast and Geodetic Survey has executed some detailed triangulation in California, in cooperation with the Advisory Committee in Seismology of the Carnegie Institution, in order to lay the foundation for studies of earth-movements in that region. An arc of triangulation extending from Pt. Reyes, California, across several fault-zones, was completed. Work on this arc had been started during the past fiscal year. Another arc was extended eastward from Monterey Bay, across several fault-zones, during the current fiscal year. The stations of these two new arcs, which are tied into the main-scheme triangulation extending along the coast of California, are placed very close together, especially near the fault-zones. The purpose of this spacing is that when the work is repeated at some future date a very exact pattern can be made which will show the amount of earth-movements in the area which may be affected.

Leveling was done in the Imperial Valley, reproducing lines of levels which had been executed in 1927 and 1928. The new leveling shows that some of the bench-marks not far distant from El Centro now have elevations differing from the original elevations by amounts that are greater than could be accounted for by the actual errors of the field-work. No report on this recent work is yet available but one will be forthcoming in the immediate future. The size of the changes in elevations is not very great but in some cases is of the order of several centimeters.

U. S. Coast and Geodetic Survey,
Washington, D. C.

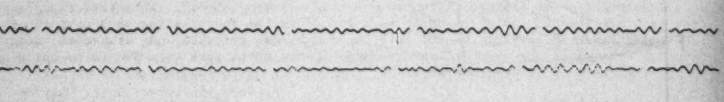
REGISTRATION OF THE TIME-SIGNALS AT GEORGETOWN

F. W. Sohon, S.J.

When the horizontal Galitzin instruments were removed to the observatory-station the difficulty of checking the clock was solved by running a wire to the astronomical observatory where the NAA 2,600-meter signals were received through a battery-operated, honeycomb coil, long-wave regenerative receiver having one stage of audio-frequency, resistance-coupled amplification feeding into a second detector consisting of a 112A tube (transformer-coupled) with 135 volts on the plate and -22.5 on the grid giving 0 milliampere no signal and around 10 milliamperes signal coming in. The plate-circuit of this tube contains the coils of a Bunnell main-line relay of 150 ohms rewound to 10,000 ohms with shellac-covered No. 40 wire. The College observatory has subsequently acquired a short-wave receiver, the output of which is fed into the transformer of the second detector of the old set. The astronomers used the break-contact of the relay to put the signals on the chronograph against the sidereal seconds of the Riefler. The department of seismology made another contact for the relay so that the shutters of the lamps are closed when the signals are coming in. The effect is seen in the accompanying portion of the record.

At the station in the quadrangle where the other instruments are located the time-signals were received by Western Union, and when this failed the broadcast signals were received by a small crystal-set. The first change was to put the Western Union signals on the vertical Galitzin record. Experience with unskilled help led to the decision to build an all-electric long-wave receiver. For the second rectifier three different schemes were tried, all of which worked, but all of which required changing the adjustment of the relay which was a No. 231-PG polarized relay obtained from Graybar.

It happened, however, that I received a visit from two gentlemen from the United States Naval Observatory whose names I do not recall, and one of them told me that he



Typical registration of time-signals on seismogram at Georgetown University

had recorded the broadcast signals by feeding the output of an ordinary broadcast receiver into a trickle-charger. On a visit to the factory of the American Instrument Company to see the triple-drum recorder they had just finished for Pittsburgh I found that they had put together some neat little rectifying-transformers to operate the shutters. These were intended to operate on 110 volts alternating-current and to deliver 3 volts direct-current. They contain a 12-volt transformer and a full-wave copper-plate rectifier. The output of a Crossly Gembox was fed into the primary of the unit and the operation was most satisfactory. We then ripped the special devices out of the long-wave receiver and made it into a standard alternating-current operated regenerative honeycomb set with two stages of transformer-coupled audio-frequency amplification. The output of the 171A tube was fed into the transformer and the rectified output was fed into the relay which has not had to be adjusted since. It was thought that greater efficiency could be obtained with a different transformer-ratio, but so much time had been spent on the work that I felt it was time to let well enough alone.

The signals show up nicely on the Galitzin records with their paper speeds of 30 mm/min, but on the smoked record that moves about 12 or 15 mm/min they are messy. I had thought of working out a relay which would open promptly and take more than a second to close. Such a relay would give the half-minute, the minute, and the 55-second signals. The matter was not followed up because we did not care to varnish and measure all the smoked records.

Georgetown University,
Washington, D. C.

THE ORIGIN OF EARTHQUAKE-WAVES

Harry Fielding Reid

Surface-waves--In the report of the California earthquake of 1906 it was shown that the transmission curve of the surface-waves did not pass through the origin but intersected the curves of the longitudinal and transverse body-waves. This suggested, what of course is evident, that the surface-waves were developed by the arrival of body-waves at the surface. There is no other way by which they could be produced, and this explanation is generally accepted (Report California Earthquake of 1906, Carnegie Inst. Washington, Pub. No. 87, v. 2, 126-127, 1910). This idea was developed further in a paper read at the Third Pan-Pacific Congress in Tokyo in 1926. It showed that it was probable that the transverse-waves were responsible for the surface-waves, whose development might be explained as in the following paragraph.

In Figure 1 let lines representing the paths of the rays be drawn from the focus F, so that hb, kd, etc., are equal to the wave-length of the body-waves. On the arrival of these waves at the surface, the latter would be set in motion with the points a, b, c, etc., all in the same phase, and the points between them in intermediate phases, so that the surface would vibrate as though a surface-wave were passing along it, moving away from the epicenter. At this time the surface-wave is a forced vibration having the period of the body-waves, but its wave-length would be bc/sin e, if e is the angle of emergence. But since e varies with the distance from the epicenter, the surface-waves would not be regular, but would vary in wave-length. There is one region, however, where the irregularity would be very small, namely, in the neighborhood of the point when e is a maximum. That such a point exists is evident from the fact that e equals 0° at the epicenter and at the antipodes and is more than 0° everywhere else. A quite regular set of forced surface-vibrations would thus be set up with the point where e is a maximum near the middle. When the disturbance ceases and the body-waves disappear from the surface

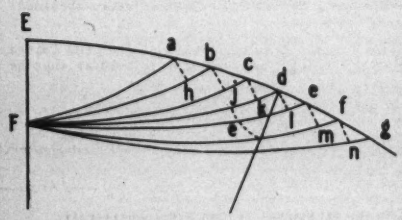


Fig. 1

by reflection, the surface-waves would advance to distant stations with their own natural velocity. Surface-waves would be produced in this way, both by the longitudinal and the transverse body-waves, but the latter have from five to ten times the amplitude of the former and probably are responsible for the surface-waves recognized in the seismogram. Moreover, their wave-length and period correspond fairly well with the surface-waves we know.

If the transverse body-waves vibrate in a vertical plane Rayleigh waves would be developed; if they vibrate in a horizontal plane Love waves would be developed; and vibrations in other planes would develop both types. We should, therefore, expect Rayleigh waves if the movement on the fault were a dip-slip and Love waves if it were a strike-slip and both if it were an oblique-slip. The wave-length of the surface-waves would be longer than that of the body-waves ($ac = bc/\sin e$), and their velocity, as we know, is less than that of the body-waves; therefore, for both reasons, their period would be longer. All of this seems to agree with observations. The wave-lengths would be least near where e is a maximum and increase on both sides of it. Love waves apparently have longer periods than Rayleigh waves; the explanation of this is not evident.

The seismogram of a nearby earthquake begins with the longitudinal waves of rather small amplitude, which are shortly followed by large motions. Seismologists have debated whether this large motion represents the transverse-waves or surface-waves. According to the above view it represents the body-waves, which have no other way of manifesting themselves. The speed along the surface is what has been called the surface-velocity of the body-wave, a quantity more discussed thirty years ago than today. It is evidently infinite at the epicenter and reaches a minimum at the point of inflection of the transmission-curve. If this second movement were due to true surface-waves, they must have been generated by the body-waves at the surface nearer the epicenter and would advance with uniform velocity. If we had several observatories near enough to the epicenter it might be possible to learn whether the surface-velocity of this movement is uniform or not. There is another criterion which I wish especially to emphasize, as it has a direct bearing on this question. In some of the recent bulletins from St. Louis and from Pasadena, records with very small or no surface-waves are recorded with the note that the corresponding earthquakes were deep-seated. Now it is evident that the deeper the focus the smaller will be the maximum angle of emergence and the longer the wave-length and period of the surface-waves. In the limit, if the focus were at the center of the Earth the angle of emergence would everywhere be zero, and the surface wave-length would be infinite. In a deep-seated earthquake the surface-waves, after being developed in the neighborhood of e maximum, would advance with a period so much longer than the proper periods of our seismographs that their magnification would really be a diminution of amplitude and they would either not be recognized at all or would have very small expression on the seismogram. Long-period waves have been recorded by Professor Imamura s long-period seismograph, but I do not know if they were related to deep-seated foci.

On the other hand, if the second movement is due to surface-waves traveling from the neighborhood of the epicenter the depth of the focus should have no influence on the relative intensities of the body-waves and the surface-waves.

When a body-wave arrives at the surface its energy is distributed into several other waves, namely, the reflected transverse-wave, the reflected longitudinal-wave, the Rayleigh wave, and the Love wave. The distribution will depend, among other things, on the angle of incidence, or, as seismologists usually call it, the angle of emergence. From the symmetry about the point of maximum e we should expect the surface-waves there to have their maximum or minimum amplitude. Professor Nakano has studied the origin of the surface-waves purely by means of the mathematical theory of elasticity and has concluded that they originate at some distance from the epicenter and form a group with maximum amplitude near their center, dying out on each side, so that the beginning of the group cannot be accurately determined (H. Nakano, On Rayleigh wave, Contrib. Cent. Met. Obs. Tokyo, 1928, I, 1-94; it is gratifying that the conclusions I have reached by general physical considerations agree very well with Dr. Nakano's). This suggests that the surface-waves will be given their maximum amplitude near where e is maximum.

In determining the velocity of surface-waves we should divide the difference in the distance from the origin of two stations beyond the point e maximum by the difference in the time of arrival of the waves, and should not use the whole distance from the origin and the time-interval since the occurrence of the earthquake. And, moreover, we should use, not the beginning of the waves but the time of maximum amplitude; for the waves develop slowly in the seismograph and the point where they will apparently begin will depend on the intensity of the responsible earthquake. This has been noticed by M'lle. Dammann (Contribution a l'étude des longues ondes, Pub. Bur. Cent. Seis. Internat., Ser. A, Fasc. 5, p. 86).

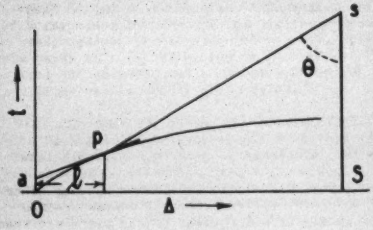


Fig. 2

We can find the distance of e maximum from the origin graphically or analytically. Suppose we draw the transmission-curve of the S-waves (see Fig. 2) and at the distance of a distant station erect a line Ss so that s represents the time of arrival of the surface-waves; lay off the angle θ so that tan θ = the velocity of the surface-waves, then the point p will mark the place and time of origin of the surface-waves. The line ps is, of course, the transmission-curve for surface-waves. Analytically, assume the point p approximately in its right place; we can then represent the neighboring part of the transmission-curve of transverse-curves by the expression $t = a + b\Delta$, where Δ is the distance from the epicenter and a and b are constants for that part of the curve. Then the time of arrival of the surface-waves at a distant station will be given by

$$T_1 = T_o + a + b\Delta + (\Delta - \Delta)/V$$

therefore

$$\Delta = [(T_1 - T_o - a)V - \Delta]/(bV - 1)$$

where T_o = time of the earthquake, T_1 = time of arrival of the surface-waves at the station, Δ = distance of station from epicenter, and V = velocity of surface-waves. The same units must be used as are used in drawing the transmission-curve.

So we have this picture of the field: Between the epicenter and the point p the surface-waves cannot keep up with the great surface-velocity of the body-waves and the surface-disturbance is due to the arrival of body-waves. The seismogram records first the arrival of body-waves, and after them probably somewhat confused surface-waves. Beyond p the regular surface-waves begin to appear and become more distinct for a short distance, and hold their amplitude better than do the body-waves, because they expand in two dimensions only, and also on account of the curvature of the Earth and refraction.

Transverse body-waves--It is so evident that these waves are principally due to slipping and friction on the fault that they need not be further discussed, except to notice that the direction of the vibration is determined by the direction of the fault-slip. And vice versa, the direction of movement on the fault may be inferred from the observed direction of the transverse-waves.

Longitudinal body-waves--The irregular friction at the fault would undoubtedly cause bumps and jars that would give rise to compressional and rarefactional waves. The seismograms show that they have only from one-fifth to one-tenth the amplitude of the transverse waves. Jeffreys (On two British earthquakes, Mon. Not. R. Astr. Soc., Geophys. Sup., July 1927) has suggested that the most important of the P-waves recorded is developed by the reflection of S-waves arriving at the surface, that is, that they are not P-waves at all but are SP. It is clear that waves of this kind must be developed and both Jeffreys and Byerly (The California earthquake of November 28, 1929, etc., Proc. Nation. Acad. Sci., v. 17, 91-100, 1931) have recognized them. Where the vertical component of the transverse-vibration is strong its larger amplitude might give rise to SP-waves stronger than the direct P. But where the transverse-

vibrations are parallel with the surface, no SP-waves should be generated. The almost pure strike-slip of the San Andreas fault in 1906 would be expected to develop transverse-vibrations parallel with the surface and therefore not to give rise to any SP-waves. A rapid examination of the published seismograms of that earthquake and the North Pacific earthquake of August 16, 1906 (Published by the Central Bureau of the Internat. Seis. Assoc., Strasbourg, 1907), and the Indian earthquake of April 4, 1905 (Pub. Earthquake Invest. Comm. in For. Languages, No. 23, Tokyo, 1907), failed to show any definite difference in the ratio of the longitudinal- and transverse-waves in the three cases. This is by no means conclusive; for on account of the variety of P- and S-waves I think the comparison should be limited to near earthquakes and that actual earth-amplitudes and not the simple seismogram-records should be used. This matter is interesting and it requires more theoretical and observational study.

Johns Hopkins University,
Baltimore, Maryland

REPORT ON PROPOSED ESTABLISHMENT OF A SEISMOLOGICAL OBSERVATORY AT HUANCAYO, PERU

(Read by the Secretary)

Advice has been received by the Secretary of the Section of Seismology regarding action taken to realize the resolution of the American Geophysical Union at its eleventh annual meeting to establish a seismological station at Huancayo. Upon the recommendation of Dr. A. L. Day, Chairman of the Advisory Committee in Seismology of the Carnegie Institution of Washington, of Captain R. S. Patton, Director, United States Coast and Geodetic Survey, and of J. A. Fleming, Acting Director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, an appropriation was made available by the Institution as a supplementary allotment in support of the seismological research for the purpose of establishment and maintenance of a seismological station at the Huancayo Magnetic Observatory in Peru, this apparatus to be installed and operated by the Department of Terrestrial Magnetism as an agent for and in cooperation with the Advisory Committee in Seismology of the Carnegie Institution of Washington. The plans for the necessary building and equipment are already under way.

This installation at Huancayo doubtless will render an important practical service in cooperation with stations in the United States in locating accurately all the more severe shocks at the Isthmus of Panama, in addition to the important contribution to seismology for the Earth as a whole, and especially for the Pacific region. The seismograms obtained are to be first sent to the United States Coast and Geodetic Survey for the compilations of that Bureau and will then go to the Advisory Committee in Seismology of the Carnegie Institution of Washington for further investigation.

REPORT OF PROGRESS ON ACCELEROMETER FOR RECORDING EARTHQUAKE-SHOCKS

G. L. Hosmer

In the summer of 1930 the Civil Engineering Department of the Massachusetts Institute of Technology undertook to design and construct an accelerometer capable of recording an earthquake-shock at a point comparatively near the epicenter. Mills W. Braunlich was appointed Research Associate in the Department to carry out this project.

The instrument is essentially a torsion-pendulum, the "inertia-mass" being mounted eccentrically on a taut wire similar to that used in the Wood-Anderson seismometer. The particular form of the inertia-mass is that suggested by Dr. Frank Wenner of the Bureau of Standards. It consists of a rectangular metal loop about 1 inch by 3/8 inch, the longer side being attached to the supporting wire, which is 4 inches in length. The free-period is one twenty-fifth of a second. That side of the loop which is farthest from the torsion-wire is made of sheet copper one-hundredth of an inch thick, bent into a curve so that it can vibrate between the poles of a magnet. The air-gap is one thirty-second of an inch. In the experimental instrument an electromagnet was used in order to permit variations in the damping-action; this will be replaced later by a permanent magnet. In addition to the magnetic damping, it was found necessary to use

special damping to reduce lateral ("violin-string") vibrations of the wire. This was accomplished by placing bits of felt, soaked in oil, just above and just below the inertia-mass.

A mirror is fastened to the inertia-mass, and a ray from a galvanometer-lamp is reflected by this mirror through a fine slit onto the paper on which the photographic record is made. As the instrument is now adjusted a deflection of eight-tenths of an inch on the paper corresponds to an acceleration equal to that of gravity.

The recording mechanisms used in testing this instrument were improvised and are suitable for laboratory purposes only. One recorder gives a photographic record of the angular displacement of the inertia-mass of the accelerometer; the other records the movements of the shaking-table. This particular table (motor-driven) was not originally made for this kind of work and is far from ideal. The table-motion is clearly not harmonic and it shows a number of small but rapid changes in acceleration doubtless caused by lost motion.

The preliminary tests seem to show that the accelerometer-curve gives accelerations that correspond closely to those derived from the displacement-curve of the table. The curves showing displacements of the table have been differentiated, and velocity- and acceleration-curves constructed. The latter curve seems to show that while the accelerometer-curve records the principal accelerations it does not show clearly the small rapid changes in acceleration. This is not surprising in view of the comparatively long period of the instrument. The method used in transforming the curves, however, is a primitive one and hardly capable of great accuracy.

The present instrument will probably be modified by using a torsion-wire having a temperature-coefficient more nearly equal to that of the frame of the instrument itself, thereby permitting a greater range of temperature without much change in the tension on the wire.

A device has been constructed for starting the recording mechanism whenever there is a shock of sufficient force to break an electric contact. This apparatus has not been given an actual trial, but no difficulty is anticipated. The instrument will start recording whatever the direction of the shock may be.

No attempt has been made thus far to mark exact time on these records. For the present the time will have to be derived from a chronometer on a clock checked by radio signals. If continuous broadcasting of time can be established, this will render the use of the chronometer unnecessary.

Preliminary studies are also being made for the design of an accelerometer having a period of about one two-hundredth of a second. The form of suspension and the damping contemplated are quite different from those in the instrument just described. This short-period instrument, if it can be constructed and operated successfully, should be able to show the rapid vibrations missed by the slow-period instrument.

Massachusetts Institute of Technology,
Cambridge, Massachusetts

PROGRESS-REPORTS ON DEVELOPMENT OF INSTRUMENTS

Vertical-component seismometer

Frank Wenner

From time to time during the past few years attention has been given to the design and construction of a vertical-component seismometer. This is intended to have operating characteristics matching those of the horizontal-component seismometers developed in the Bureau of Standards. The general dimensions are about the same as those of the horizontal-component instruments while the electromagnetic system is the same for both.

The suspension-system follows in part a suggestion of Professor Lewis F. Richardson of Scotland. There are three springs, the principal one of which applies an upward

force for supporting the steady mass. .This force is applied to the moving system at a point in the plane passing through the axis of rotation and the center of mass. The action of this spring is at least approximately symmetrical about the equilibrium-position while changes in its tension changes the equilibrium-position. This spring acting alone would result in a rather short period so a second spring is used for lengthening the period. The second spring acts approximately through the axis of rotation and produces a displacing moment approximately proportional to the displacement. Independent adjustments of the two springs give practically independent adjustments of the period and equilibrium-position. However, the second spring causes displacing moments slightly greater than the first power of the displacements so a third spring, which is very small,is used to compensate this defect.

Except for a device to compensate for the change in the stiffness of the springs with changes of temperature the apparatus is assembled and ready for preliminary tests.

Shaking-table

F. Wenner and H. E. McComb

A year ago a shaking-table was planned for testing small-size horizontal-component seismometers. This consists of a triangular slab of concrete about a meter on a side supported at the corners by parallel wires which in turn are supported by extensions from the pier, which has been used in seismometry work at the Bureau of Standards. The three wires will be of such length as to give a free period of about one-quarter second and of equal length so as to give no tilting except as the pier may tilt as a result of the forces applied to cause displacements of the slab. The means employed for displacing the slab applies at each instant a force in the opposite direction to pier so for static conditions there is no resulting tilting-moment. The uncompensated tilting-moment which is proportional to the acceleration presumably will not be serious, since for long-period movements of the slab it is relatively small and for short-period movements the sensitivity of seismometers to tilting is small.

Reduction-gears and cams are provided for applying varying forces to the slab and the resulting motion will be magnified from 500 to 1,500 times by mechanical and optical means. Simultaneous records of the magnified motion of the slab and of the galvanometer will be made photographically on the same sheet of paper. Most of the construction work on this apparatus has been completed.

Accelerometer

Frank Wenner

Detail drawings for an accelerometer for use in regions of strong earthquakes have been completed and it is expected that shortly an instrument-maker will be giving his entire time to the construction. Work on a recorder for use with the accelerometer is under way in the United States Coast and Geodetic Survey, so it is expected that good progress will be made.

As the general plan for this apparatus was presented a year ago at a joint meeting with the Eastern Section of the Seismological Society of America and published in the proceedings of that meeting, only a few points need be mentioned at this time. The suspension-system is not to be of the torsion-type but will consist of eight rather fine wires, four attached to one end and four to the other end of the moving system so as to give a short period (about one-tenth second) and at the same time make the system fairly rigid except for movements about the axis of rotation. The magnet for damping the principal motion of the system will be of cast cobalt steel.

This work should not be thought of as duplicating that in progress at the Massachusetts Institute of Technology. The instruments being developed there have very different operating characteristics.

U. S. Bureau of Standards (F.W.),
Washington, D. C.

U. S. Coast and Geodetic Survey (H.E.M.),
Washington, D. C.

THE DEVELOPMENT OF A TILT-METER

George E. Merritt

An experimental tilt-meter operating on the interferometric principle has been designed and constructed at the Bureau of Standards. Since this instrument may prove of service in the investigation of seismic phenomena, a description of it will be of interest to this Section.

The tilt-meter consists of a static vertical pendulum, liquid-damped to eliminate vibrations and all short-period effects, which carries the reference-plane, and another plane which is laid directly on the Earth and which should tilt with the adjacent strata. Interference is obtained between these two planes and the angle between them is measured by counting the number of interference-bands across a circle of known size scribed on one of the planes.

Readings on a single instrument serve to give the direction and amount of the resultant tilt as well as the component of tilt in any direction. The maximum measurable tilt is about 400 times the smallest distinguishable tilt and several ranges may be covered by a single instrument simply by using different size circles on the same plate. For a four-centimeter circle one-tenth fringe means an angle of 0.15 second. The accuracy is the same for all sensitivities.

In the present instrument the pendulum consists of a hollow cylinder of fused quartz 35 cm long by 5 cm inside diameter with an optically polished fused quartz-plate attached to the lower end. The lower surface of this plate is approximately horizontal and constitutes the reference-plane. The pendulum is supported in a gimbal, the trunnions of which consist of four sets of crossed ribbons on spring bronze. The gimbal is attached to a cylindrical case which protects as well as supports the working parts. Thermal or time-changes in this support should not affect the readings of the instrument.

The lower, or tilting-plate, is laid directly below the pendulum with the adjacent surfaces of the two plates nearly parallel and about 2 mm apart. The lower plate is in immediate contact with the rock or other surface to be investigated with no metallic leveling-device (which might introduce errors) intervening.

The fringes are viewed through the pendulum from above by means of a separately mounted illuminating- and viewing-instrument of the Fizeau-Pulfrich type carrying a helium lamp. Movements and readjustments of this viewing-instrument do not affect the accuracy of the readings.

As constructed, the instrument has proved to be very stable and seems not to be permanently affected by vibrations and jars of reasonable intensity. The fringes are clear and steady under the normal conditions of an inhabited building and are easily counted.

So far, no place has been found, even in the deepest sub-basements available, where there is not some indication of tilting. A second instrument, is therefore, being built of slightly different dimensions and the two will be set on a common base. If, then, the readings on the two instruments agree, all the indicated tilt may be assumed to be real and not the result of instrumental error.

For investigation of tilts in connection with earthquakes, it will be desirable to set the instruments in pits of different depths out through loose material to the stratum which might be expected to move more or less as a unit. Different depths can be suited to the topographical or climatic conditions as the focal length of the viewing-instrument can be accommodated to various distances.

U. S. Bureau of Standards,
Washington, D.C.

PROGRESS-REPORT ON DEVELOPMENT OF SEISMOLOGICAL INSTRUMENTS

H. E. McComb

During the past year attention has been confined particularly to the details of construction of six large, non-tilt seismographs; the development and test of a working model of a non-tilt seismometer having a steady mass of about one kilogram and provided with magnetic damping and photographic registration; the design and completion of seismograph-recorders for teleseismic work; the development of suitable circuit-makers of reliable and convenient type for use on standard pendulum-clocks to be used in making time-marks on seismograms; the construction of reliable, low-frequency receivers for time-reception at stations located at considerable distances from Arlington and Annapolis; and cooperation with other institutions in preparation of plans and specifications for seismological equipment and observatories or in the improvement of existing stations. Briefly, these different projects are described below.

(a) The large, non-tilt seismographs are 25-kilogram horizontal pendulums rebuilt and designed for tilt-compensation, optical magnification and oil-damping. Nominal static magnification is about 75. The original recorders have been equipped with necessary lenses, light-sources, etc., for photographic registration. The paper speed on these recorders is 15 mm/min. Instruments of this type are now in operation at Columbia, South Carolina, and at Bozeman, Montana. The third set is to be installed in the near future at Ukiah, California.

(b) In addition to the single seismograph-recorders developed and manufactured by the American Instrument Company for the San Juan Magnetic Observatory, this Company has completed a large, clock-driven recorder with a drum having a 14-inch face for use with two horizontal components of the Wenner type at Sitka, Alaska. Two components will be recorded on the same paper. The paper speed is 16 mm/min and the shaft is designed for a 26-hour run.

(c) The circuit-makers are quite reliable and the duration of the contact-interval is continuously adjustable from a small fraction of a second to four seconds for the minute-signal and from about four seconds to forty seconds for the hour-signal. Adjustments may be made from the front of the clock-dial without interruption of the clock. The noon and midnight hour-signals are eliminated, thus serving to make a positive identification of the hour.

(d) Low-frequency radio receivers have been found to give quite reliable results at great distances from Arlington and Annapolis. A convenient type, having a wide range of adjustments, has been developed for use at San Juan and Tucson.

(e) A small, non-tilt seismometer has been constructed and operated with some success during the year. It has a 2.4-pound steady mass (approximately one kilogram) and is provided with magnetic damping. Further development and refinement of this instrument is in progress and it will be provided with equipment for operation at high or low magnifications separately or simultaneously as desired.

(f) Cooperation with the University of Pittsburgh in the establishment of a seismological station has been carried out with the result that two horizontal components of the Wenner type are now in continuous operation. Records are being made on a three-drum recorder which gives a paper speed of 30 mm/min and is driven by a synchronous motor from local power-line. This recorder was developed by the American Instrument Company.

(g) Some progress has been made in the study of a design of an inexpensive shock-recorder for use in the vicinity of destructive earthquakes.

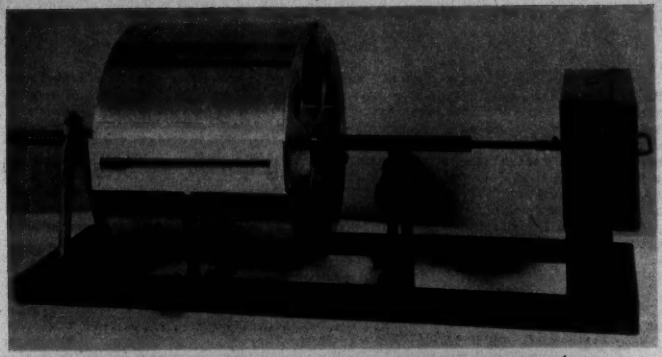


Fig. 1--Seismograph-recorder, 9-inch face, paper-speed 16 mm/min

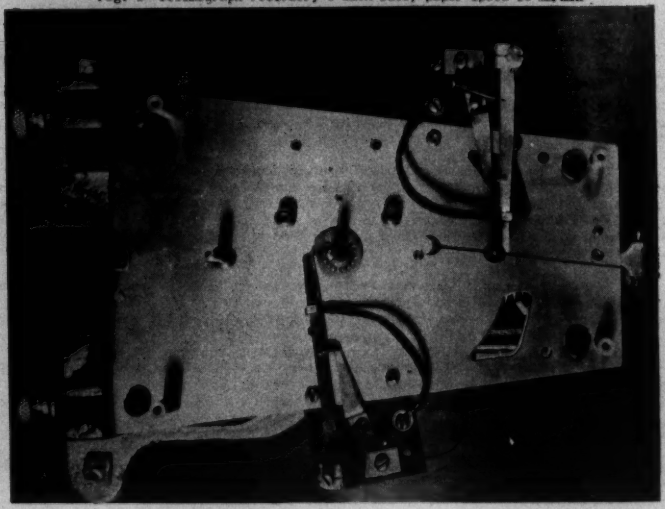


Fig. 2--Circuit-makers for pendulum-clocks

U. S. Coast and Geodetic Survey,
Washington, D. C.

REPORT ON THE CONSTRUCTION OF A THREE-DRUM SEISMOGRAPH-RECORDER

W. H. Reynolds

General description--Each drum has a separate light-source as shown in Figures 1 and 2. The light emerges through a vertical slit directly in front of the lamp-filament and strikes the mirror on the seismometer. It is reflected back through a spherical condensing-lens onto the cylindrical lens shown in its rectangular mounting. This lens has a focal length of 2.6 cm and focuses the beam from the seismometer-mirror onto the drum in the form of a sharp round spot of light. Each lamp has also a relay mounted directly under it which carries a vertical arm ending in a small plane lens set at an angle of 45° to the axis of the emerging beam. In normal operation this is held by gravity out of the path of the beam until the clock energizes the relay, when for an instant it is drawn into such a position that the beam is refracted slightly, thus causing a displacement of the record. By this arrangement there is no actual cutting off of the light and the timing-marks while slightly displaced are plainly visible.

The bromide paper is held on the drum by a narrow piece of glass which slides under clips mounted on the edge of the drum. This arrangement is one that lends itself to ready adjustment in the dark-room. This glass causes no visible distortion of the record.

The lamp, relays, and cylindrical lenses may be easily adjusted in all three planes.

The main shaft of the instrument has a lead-screw cut integral with it. A sector mounted in the left-end bearing engages this screw and causes the lateral motion of the drum as it rotates. By lifting a button, this sector may be disengaged and locked in its free-position. Thus the drums may be instantly returned to their starting-positions at the end of the record.

A clutch is provided between the gear-reducer and shaft to disengage the latter when changing records or working on the drums. The frame is of a heavy angle-iron. Wires are all iron-clad, moisture- and abrasion-proof. The main relay is 150-ohm telegraph-type. The instrument may be operated from small transformer for light and a dry-laboratory rectifier for the clock-circuit or by storage-battery for both. The finish of base, gear-box, and pedestals is sage-green Duco.

The rotating assembly is statically balanced in the factory.

The overall dimensions of instrument are: Length, 104 inches; width, 19 inches; and height, 13.5 inches.

The development of both the seismometer and seismograph has been done with the kind cooperation of the United States Coast and Geodetic Survey.

Specifications for three-component optical seismograph-recorder--The following is a list of specifications for three-component optical seismograph recorder:

(1) Drive--The drive is a synchronous ball-bearing General Electric motor taking power from frequency-controlled source of alternating-current; the motor-speed is 1,800 revolutions per minute.

(2) Gear-reducer--The gear-reducer is 57,000:1 with three sets of worms and worm-gears running in oil; the high-speed shaft is ball-bearing; the intermediate and slow-speed shaft is in bronze journals; the housing is of cast iron.

(3) Shaft--The drive-shaft is 3/4-inch diameter, cold-rolled steel with one end fitted with bronze bushing with square hole to take square drive-shaft from gear-reducer.

(4) Drums--The drums are of sheet aluminum with rolled aluminum-ends; the drum-circumference is 900 mm and length 29.5 cm; the speed of drums is two revolutions per hour with lateral travel of one-fifth inch per revolution once in 25 hours; the whole moving-system is statically balanced.

Fig. 1--Motor-driven, three-drum seismograph-recorder

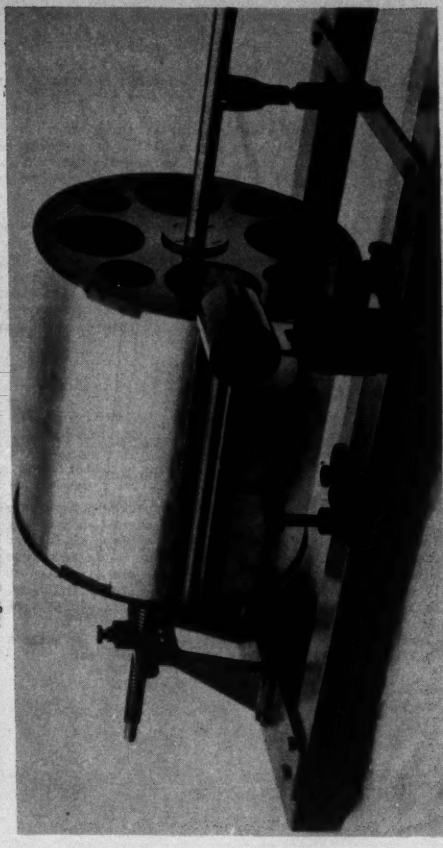


Fig. 2--Detail view of one drum of recorder shown in Figure 1

(5) Light-source--The light-source is a straight-filament, 3.4-volt Mazda lamp housed in optically black brass cylinders.

(6) Time-record--The time-record is from a Seth Thomas No. 70 clock, movement 68, 60-beat, with special variable impulse-contact each minute.

(7) Record--Bromide paper giving a sharp contrasty line is used for the record.

American Instrument Company,
Washington, D. C.

OBSERVATIONS OF DEVELOPMENTS IN INSTRUMENTS AT THE SEISMOLOGICAL RESEARCH LABORATORY IN PASADENA

N. H. Heck

During a recent visit to the Seismological Research Laboratory at Pasadena, the following new developments in instruments were noted:

A new vertical-component seismometer of short period by Hugo Benioff. This has the characteristic of giving high magnification to the preliminary phases. A device for measuring the change in phase of an earthquake wave while traveling the length of a stationary long pipe, also by Benioff. J. A. Anderson is developing a relatively simple pipe device containing liquid as a stationary mass which gives promise and he is also developing a simple intensity-meter which if successful will solve the problem of local measurements of maximum intensity of an earthquake-shock. There is also a device for increasing the brightness of the light at the time of the earthquake so as to improve the photographic recording. It was stated that high accuracy is being developed in the determination of earthquake epicenters in the case of moderate local shocks. The element of time is important. The standard electrical apparatus nearly meets the requirements of accuracy of one-tenth of a second while the Henson clock is probably nearly adequate to meet this need. Interest was expressed in the more frequent broadcasting of correct time.

U. S. Coast and Geodetic Survey,
Washington, D. C.

MEMORANDUM ON THE NEW YORK EARTHQUAKE OF APRIL 20, 1931

Frank Neumann

The New York earthquake of April 20 appears to have originated along a fault coincident with Lake George which is a long, narrow body of water lying in a line roughly 30° east of north. The shock has been reported as felt at about 100 localities and reports are still coming in. The regions of maximum intensity are all in the region of Lake George and the isoseismal lines are elongated in such a way as to indicate relatively equal intensity throughout the length of the lake. If any part is given preference in point of maximum intensity it would probably be the southern end.

The instrumental evidence is not sufficiently definite to improve on the accuracy of the location as determined from the isoseismal map.

U. S. Coast and Geodetic Survey,
Washington, D. C.

AMERICAN GEOPHYSICAL UNION

Twelfth Annual Meeting

REPORTS AND PAPERS

S E C T I O N O F M E T E O R O L O G Y

Washington, D. C.
April 30, 1931

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THE FIRST INTERNATIONAL POLAR YEAR OF AUGUST 1882 TO AUGUST 1883

Alfred J. Henry

The history of the first International Meteorological Polar Year has been given so frequently that only a bare outline will be presented of the events that led up to the formulation of a program and the assignment of territory to be occupied by the two conferences held in Hamburg in 1879 and at Rome in the succeeding year.

The idea of establishing a ring of meteorological stations around the North Pole was first put forth by Lieutenant Carl Weyprecht of the Austrian Navy. Weyprecht, who with his fellow Lieutenant Julius Payer were members of the second Tegethoff Expedition fitted out for arctic exploration by Count Wilczek in 1872, evidently had a background of arctic experience. Payer may be remembered as the discoverer of Franz Josef Land on that expedition.

Weyprecht presented his plan before a large meeting of naturalists held at Grats, Austria, on September 18, 1875. The idea was favorably received by the heads of meteorological services in Europe; further consultation and consideration led to the holding of an international polar conference at Hamburg in 1879 under the presidency of Dr. George Neumayer, at which the various European nations were represented. A second conference was held in Berne in 1880.

It was agreed at these conferences that each nation should establish one or more stations as near the Arctic Circle as might be practicable where continuous meteorological and magnetic observations should be made for the year ending with August 1883. Very elaborate instructions were approved and distributed by these conferences. The stations finally arranged for the north polar region were as follows: Norway, Bossekop, Altan Fjord, Norway; Sweden, Ice Fjord, Spitsbergen; Holland, Port Dickson, mouth of Yenisei, Siberia; Russia, Sagastyr Island, mouth of Lena River, Siberia, and Novaya Zemlya, north latitude 72°23; Finland, Sodankyla, Finland; United States, Point Barrow, Alaska, and Lady Franklin Bay, north latitude 81°44; Great Britain, Great Slave Lake, Canada; Germany, Cumberland Bay, west side of Davis Strait; Denmark, Godthaab, Greenland; and Austria, Jan Mayen, north latitude 71°.

The general plan was carried out with the exception of the part assigned to the Dutch. The vessel carrying that party was beset by ice in Kara Sea and finally sank in June 1883. With fine spirit the leader of the party continued observations and eventually reached Novaya Zemlya by boat and sledge. The Austrians also had difficulty in reaching Jan Mayen and the disaster that overtook the Greely party in its retreat to Cape Sabine and wintering at that place is too well known to be repeated here.

In the Southern Hemisphere the Germans occupied a station in South Georgia and the French another one near Cape Horn. Each cooperating nation published its results in extenso, but in the majority of cases there was no discussion of the raw material. The set of final reports are embraced in some twenty quarto volumes which may be consulted in the larger meteorological libraries.

U. S. Weather Bureau,
Washington, D. C.

THE SECOND INTERNATIONAL POLAR YEAR, 1932-1933

Herbert H. Kimball

During the year August 1932 to August 1933, the fiftieth anniversary, or the jubilee of the first International Polar Year, 1882-1883, is to be appropriately celebrated. It is proposed that as far as possible the different nations shall reoccupy the stations occupied by them in 1882-1883. Many new stations will be opened, and the observational program greatly extended over that of fifty years ago.

The project is sponsored by the International Meteorological Organization, which includes in its membership the directors of meteorological services and observatories. A Commission has been appointed, of which Dr. la Cour of Denmark is Chairman, to have charge of the preparation of the program.

The following International organizations are cooperating with this Commission: The International Union of Geodesy and Geophysics; a special Commission of the International Union of Geodesy and Geophysics; International Commission for Solar Radiation; International Commission for the Study of the Clouds; and the Permanent International Commission for the Exploration of the Sea.

The Meteorological Program--The weather and its changes are influenced by atmospheric conditions prevailing over the entire hemisphere, and perhaps over the entire globe. Generally speaking, the equator is the hot cylinder of the atmospheric engine, the polar regions are the cold cylinders, or condensers, and the Sun supplies the heat. In temperate latitudes we are under the influence of the atmospheric circulation between the equator and the poles, which is continually maintained by this engine. Evidently, in order to thoroughly understand this circulation we must know the conditions not only in temperate regions, which are now quite well represented on daily weather-maps, but also in equatorial regions, or in the hot cylinder of the engine, and in the polar regions, or in the condensers of the engine.

We know a great deal about equatorial regions, but comparatively little about polar regions. Meteorological observations within the Arctic and the Antarctic circles are, generally speaking, fragmentary, and over most of both of these regions the weather-map is blank. The major project for meteorology during the polar year, therefore, is the study of the atmospheric circulation between the equator and the poles. To facilitate this study it is proposed to extend the existing network of stations northward within the Arctic Circle, and, as far as practicable, southward within the Antarctic Circle. These stations will be in communication with the outer world by radio, and will transmit weather-reports regularly for entry on the synoptic weather-maps. Thus the reports become immediately available for use in weather-forecasting and in meteorological studies.

In the southern hemisphere, besides the stations on the South Orkneys, reliance must be placed principally on the cooperation of whaling-vessels. In the northern hemisphere the governments of the leading nations are cooperating to establish a complete network of stations about the poles and to intensify certain phases of the work at favorably located stations in lower latitudes. Already the maintenance of about 60 stations in high latitudes seems to be assured, of which at least 12 are above latitude 70° north.

It will be a source of gratification to Americans that both Point Barrow, the northernmost point in Alaska, and Fort Conger on Lady Franklin Bay (General Greely's farthest north permanent station) will probably be occupied by Americans in 1932-33. Point Barrow is now on the list of permanent stations in Alaska, and plans are well advanced for occupying Fort Conger by a privately financed expedition.

The program includes not only observations at surface-stations, but also aerological observations. Pilot-balloons will be employed to determine the direction and velocity of the wind, and several nations have signified their readiness to use airplanes in obtaining meteorological data at high levels, and especially the temperature and the humidity of the air. Since observations by balloons and airplanes cannot give continuous records, it is proposed to install continuously recording instruments at mountain stations in high latitudes. One of these will be on a mountain in Spitzbergen at latitude 78° north.

Finally, the special Commission of the International Union of Geodesy and Geophysics, with Professor Störmer of Norway as President, will specialize in a study of the aurora, and for that purpose their observing stations will all be provided with cameras, plates, and spectroscopes of equal sensitiveness. In general, every effort will be made to insure accuracy of apparatus that will be employed and uniformity in the treatment of data that is obtained.

U. S. Weather Bureau,
Washington, D. C.

CONTRIBUTIONS OF THE UNITED STATES WEATHER BUREAU TO THE PROGRAM OF THE SECOND INTERNATIONAL POLAR YEAR

C. F. Marvin

Dr. Kimball has so clearly outlined the general character of the program that it is unnecessary for me to say more than that the Weather Bureau is anxious to cooperate as fully as possible in the accomplishment of the main objective. As has been emphasized, the program is one that includes the entire circumpolar hemisphere, both about the North Pole and the South Pole, although our part of it is related strictly to governmental possessions in North America, which include Alaska.

Without going into full details as to just what additional observations might be required, it is believed that the Bureau can furnish all that the program calls for, with little variation from its regular daily program of observations at the 200 or more stations in continental United States, including Alaska. No special appropriation of funds has been secured for this purpose, and in fact none is believed to be necessary.

The extension of the work of the Weather Bureau in Alaska during the past two years, incident to providing a rather comprehensive program of service for aviation, will aid materially in supplying observations in the high latitudes called for by the polar-year program. We will, in fact, have quite a complete station at Fairbanks, Alaska, and may be able to make certain special upper-air observations possibly by means of sounding-balloons at this point or by airplanes equipped with particular instruments. In addition, there will be many stations throughout the United States and some in Alaska that will make regular observations with pilot-balloons, also frequent surface-observations. The United States is not in a position to establish any mountain stations, either in the states themselves or within Alaska, and we have some doubts as to the usefulness of such observations. We also will not be able to secure aerological observations from ships at sea. Finally, our program will be confined exclusively to meteorological observations, including those in the free air, without reference to terrestrial magnetism, aurora, and other phenomena.

It has been felt from the beginning that special expeditions, involving special appropriations and uncertain expenses, would not be required in order that the Weather Bureau should be able to make a very substantial contribution to the whole program of the polar-year work, and we look forward with interest to the details of the proposed program in order to adjust our work as completely as possible to what it may entail.

U. S. Weather Bureau,
Washington, D. C.

CONTRIBUTIONS OF THE METEOROLOGICAL SERVICE OF CANADA TO THE PROGRAM OF THE SECOND INTERNATIONAL POLAR YEAR

J. Patterson

(Abstract)

It is hoped that in the Polar Year Canada will be able to carry out the program assigned to her by the International Polar Commission, that is, to have a fully equipped magnetic station at Chesterfield Inlet, where a complete set of magnetic, meteorological, and auroral observations can be made.

It is probable that a boat will be wintering in the neighborhood of Copper Mine, and if so, it will be utilized to establish a suitable base in order to measure the height of the aurora. In addition, Copper Mine will maintain a complete meteorological outfit and possibly instruments for measuring the temperature of the air to considerable heights.

There will also be stations established at Aklavik, Fort Norman, and Fort Simpson, where complete meteorological and pilot-balloon observations will be made.

Meteorological Service of Canada,
Toronto, Canada

REPORT OF THE MADRID MEETING OF THE INTERNATIONAL COMMISSION FOR THE EXPLORATION OF THE UPPER AIR

W. R. Gregg

This meeting was held during the week March 16 to 21, 1931. There were about twenty delegates, representing ten European meteorological services and the United States Weather Bureau.

The chief subjects considered were cooperation with the International Polar Year Commission, the study of explosion-waves, and the publication of upper-air data obtained on International days. Dr. H. Hergesell, President of the Upper-Air Commission, appointed sub-commissions to take up these subjects in detail and formulate resolutions to be reported back to the Commission for action. The chairmen of these sub-commissions were: D. la Cour, polar year; F. J. W. Whipple, explosion waves; and R. G. K. Lempfert, publication.

At the final meeting of the Commission on March 21 some forty resolutions were passed, including those submitted by the three sub-commissions and a few others on miscellaneous topics. All of these will be published later in the Procès verbaux of the Commission. A brief summary of the more important ones follows.

Polar year--The discussion centered around the resolutions concerned with meteorological investigations, which were passed at the Leningrad meeting of the International Polar Year Commission in 1930, and the selection of International days for the Polar Year.

The Leningrad resolutions of most interest to the United States are Nos. 15, 16, and 17. The first of these urges the establishment of several mountain stations in the arctic regions, including one in the vicinity of Bering Strait. No. 16 recommends five aerological stations in the arctic regions equipped for making observations of pressure and temperature, as well as wind, in the stratosphere, one of these stations to be in Alaska. The last of the three (No. 17) calls for increased activity in obtaining upper-wind data at sea by means of pilot-balloons along the lines recently inaugurated by Germany and Great Britain.

The selection of International days received considerable attention. It was decided that, for the polar-year program, it would be best to substitute for the International month a number of days for each month, in order to provide samplings of upper-air conditions throughout the year. Three sets of days, two days in each set, were selected, one being called "days of the first order," on which all services throughout the world are urged to make upper-air soundings, if at all possible. The other two sets are called "days of the second order" and "days of the third order," respectively, and these are recommended for adoption also, if practicable, but in no case are they to displace "days of the first order."

The world-wide character of this second polar-year program was emphasized, the primary purpose being to secure data for synoptic investigations rather than for statistical studies, which was the chief goal of the first polar year.

The following additional recommendations in the form of resolutions were approved: Establishing mountain stations in all parts of the world, including the western United States, Canada, Mexico, Hawaii, and the Philippines; carrying out programs proposed for a number of stations in northern Siberia and an extensive network of stations in the southern hemisphere, including some in the Antarctic; specifying hours of upper-air observations on International days.

Explosion-waves--The Chairman of this sub-commission called attention to the results of studies that have been in progress during the past three or four years in England and stated that he regarded this method the most promising of any at present for investigating temperature conditions at heights above 30 kilometers. The discussion at the meeting was concerned altogether with outlining a program for continuing and expanding this investigation. At present all of the microphone stations are to the northwest of the explosions. If some of the continental countries of Europe can cooperate, there will be stations to the south and southeast also. From the discus-

sion there is good reason to expect such cooperation. A resolution along this line was passed.

Other resolutions recommended the standardization of instrumental equipment and the adoption of a program of explosion-wave investigations by other meteorological services in all parts of the world, particularly during the polar year.

Publication--The meeting of this sub-commission was devoted to a consideration of two subjects, (1) some proposed changes in the form of publication, and (2) bringing the publication itself up to date. With regard to the first it was decided to adopt a proposal to publish the data in regional groups in such a way as to facilitate the study of conditions over an area.

The publication of upper-air data is several years behind schedule, the reason being a lack of funds. It was decided to suggest an advance of funds from the Secretariat for the purpose of publishing all data now ready, reimbursement to be made from sales of the various volumes. A resolution to this effect was passed.

Other resolutions regarding publication include one requiring that all meteorological services forward data within one year after the observations; another, that tephigrams be not included in the publication, but that they be submitted to the President of the Commission who will arrange to have photographic copies made for distribution to any one requesting them; and a third, that all services be urged, so far as practicable, to publish their own data on other than International days in the standard International form.

Miscellaneous resolutions--The Commission's action on various matters not included in the work of the three sub-commissions is indicated in ten final resolutions. There follows a summarized statement of the most important of these: Recommendation for further development of pilot-balloon investigations at sea; gratification concerning announcement that pilot-balloon observations will shortly be begun in the Canaries, at Cape Verde, Cabo Juby, Rio d'Oro, Horta, and Bermuda; recommendation for close cooperation with the Cloud-Commission, particularly during the polar year; request that the President of the Solar-Radiation Commission arrange that all institutions equipped with radiation-apparatus make observations, both of solar and nocturnal radiation, on all International days; suggestion that a list be prepared of all pilot-balloon observations that were made along the Western Front during the World War, and that action on what shall be done with the data be deferred until this list is published; recommendation for greater activity by all meteorological services in utilizing airplanes in upper-air investigations.

Scientific session--An interesting feature of the Madrid meeting was a scientific session at which the results of recent investigations were presented. Reference has already been made to two of the subjects discussed, namely, pilot-balloon observations at sea, by Admiral Dominik of the Deutsche Seewarte, and studies of explosion-waves, by Dr. Whipple of Kew Observatory. Other papers included a discussion of sounding-balloon observations to great heights at Hamburg, by Professor Wigand, and a description of a micro-meteorograph, by J. Jaumotte, Director of the Royal Meteorological Institute at Liege. A brief report was given on the work now in progress in the United States in connection with the formation of ice on aircraft.

Two subjects that received considerable attention but on which no formal action was taken were the development of a radio sonde instrument and the possibility of utilizing rocket-ascents in securing temperature data at heights from 30 to 60 kilometers. With regard to the radio sonde instrument, hope was expressed that this would be ready for quantity-production in time for the polar-year program. No definite statement can as yet be made, however.

As to the rocket-ascents, it was pointed out that this method would probably be too costly for anything like a regular service, but that, if even a small number of ascents could be made to great heights and give reliable data at those heights, they would be of great value, in view of the conflict of opinion relative to temperatures above 40 kilometers. Although no resolution on the subject was passed, the delegates were requested to report to the President of the Commission any developments or progress that might at any time come to their attention.

U. S. Weather Bureau,
Washington, D. C.

THE PROPOSED INTERNATIONAL CLOUD-ATLAS

W. J. HUMPHREYS

It is desirable that constructive criticism of the tentative form, recently issued, of the International Cloud-Atlas be made fully and promptly so that the finally adopted work may be generally acceptable. Because the old International Cloud-Atlas is out of print, it is necessary to replace it with a new set of cloud-pictures. This necessity offers also the opportunity to introduce any changes in nomenclature and description that may seem desirable.

Several changes of this nature have been made and provisionally adopted. Most of them are acceptable, but a few of them go entirely too far--at least many of us think they do. In our opinion they confuse the subject rather than clarify it, and are by no means as good as the older names and definitions to which all the world has long been accustomed. For instance, it is insisted that no matter how huge and towering a cumulus cloud may be it shall not be called a cumulo-nimbus unless and until a fibrous cirriform cloud is seen to spread out from its top.

Heretofore we have regarded precipitation from a cumulus cloud as the one and only feature that justified and required its being called cumulo-nimbus. This feature, precipitation, is an important one, while the formation of cirrus at the top of the cloud is a matter of little consequence. Indeed a cumulus cloud may yield much precipitation and yet develop no cirrus. On the other hand, it may produce abundant cirrus and give no rain. For those reasons, and others too, all of which might be greatly elaborated, many of us distinctly prefer the definition of cumulo-nimbus now in general use to the proposed new one.

Again, many of us are puzzled when we are told that we shall not call a cloud alto-stratus unless a portion of it, at least, is fibrous in form. If one person saw a fibrous patch and called the whole cloud alto-stratus what should another person call it if the fibrous portion were hidden from him by a tree or a house? The present definition of alto-stratus does not lead to such a dilemma as this, and, in our judgment, is much better than the proposed new definition.

Many of us also fail to see any need for the proposed new term "nimbo-stratus" if it is to mean (and that is the way it is defined) substantially the same thing that "nimbus" now means. We think this merely leads to unnecessary confusion. Furthermore, calling scud or fracto-stratus by the name nimbus, as is suggested, would only make the confusion more confounded.

I am sure that these comments are timely. I trust that they also are in time--in time to secure much helpful and constructive discussion of the proposed Cloud-Atlas before it takes its place among the "laws of the Medes and Persians."

U. S. Weather Bureau,
Washington, D. C.

ATMOSPHERIC TURBIDITY

F. E. Fowle

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"In recent years the investigations of Abbot and his collaborators have in a high degree attracted the interests of meteorologists to the determinations of the solar-constant and its variations. This interest is well deserved and will probably in the future result in considerable progress, especially in long-range forecasts of temperature." So wrote Ångström in 1929. He continues: "However, attention must be drawn to the fact that the variations in radiations reaching the surface of the Earth are to a much larger extent due to fluctuation in the transmissive power of the atmosphere."

A conference was held in Berlin and Potsdam, February 1931, relative to some function which easily could be used to indicate such fluctuations in atmospheric transparency. A term called "atmospheric turbidity" is generally used to designate this function.

Several years ago the writer indicated that our atmospheric transmission-coefficients, when the effects due to dry dust, wet dust, and water-vapor were eliminated, followed closely such values due solely to the permanent gaseous constituents of the air, as could be computed by Rayleigh's formula for such coefficients. This held true for our observations on the short wave-length values to about 0.37μ. For shorter wave-lengths, the observed coefficients are too great. Light scattered into the shorter wave-lengths from the longer wave-length and more intense part of the spectrum could explain this discrepancy. The writer hopes to find some method to eliminate this trouble.

This basic amount due to molecular scattering led Ångström to propose a turbidity-factor based upon this property that a portion of the transmission-coefficient should always correspond to the scattering derived from Rayleigh's formula; the remaining loss in the atmosphere being correlated with the turbidity-factor. Hence he used the expression for the solar radiation, Q, reaching the Earth

$$Q = \int_0^\infty I_0 \cdot q^m \cdot e^{-\beta/\lambda^a} d\lambda - F$$

The turbidity-term is $e^{-\beta/\lambda^a}$, β is the turbidity whose variation with the wave-length, λ, is indicated by the exponent, a. In my published work I have considered the turbidity-term composed of three sections $(a_{wd})(a_w\lambda^4)(a_{dd})$, the first giving the transmission-coefficient due to wet dust (that is, dust upon which moisture has been precipitated), the second due to the free water-vapor and varying with the fourth power of the wave-length, and the third due to dry dust. My earlier papers analyzed our earlier observations into these three together with the Rayleigh coefficients, apparently with some success.

Considering that a_w is often small compared with the a_{wd} and a_{dd} it is perhaps no inconsistency that the values indicated for Ångström's a, which combines the three factors, should be 1.33 for the average conditions at Calama. His corresponding value for β is 0.23.

A considerable part of the work done by others with this formula has used observations from the Smithsonian stations. These coefficients are based on what we call "long-methods." Only a minority of our determinations of the solar-constant are represented by them, since the very constant day necessary is rare. I believe we can attain far better results in testing and obtaining the constants of these formulas by the use of a few selected days, using several hitherto unpublished criteria for their selection. Probably the data from less than one day in ten pertains to a day good enough for these critical tests.

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MEASUREMENTS OF THE COLOR OF THE SEA AND SKY

Charles Bittinger and E. O. Hulburt

(Abstract)

On a recent voyage we went from Norfolk southward along the 75th meridian around the east end of Cuba and across the Caribbean Sea to Panama, and returned by approximately the same route. We had along the abridged edition of the Munsell Book of Color. This is a scientifically prepared collection of little colored rectangles of a series of colors throughout the spectrum, a series of different brightnesses of these colors and of saturation (or admixture of white light) with the colors. By holding the colors up against the sea or the sky it was a simple matter to find the rectangle which matched the sea or the sky in color, brightness, and saturation. Thus a record was made of these natural phenomena. It came out roughly that on clear cloudless days the sky near the horizon was about five times as bright as the sea near the horizon, and the sky 50° from the horizon was about twice as bright as the sea near the horizon. No difference in the color of the sea was observed as we entered the Gulf Stream in deep water.

Observations made on sunny days looking almost vertically down at the sea showed that the Caribbean Sea was a beautiful effulgent blue quite different from the blue-black color of the Atlantic Ocean north of the 30th parallel of latitude. Calculation from Raman's theory of the body-color of the sea based on the Einstein-Smoluchowski fluctuation formula showed that the difference in the body-color of the Caribbean and the Atlantic was not completely attributable to differences in temperature. This indicated, perhaps what was obvious, that the color-differences were partly due to other effects than temperature, such as particles either of animal, vegetable, or mineral origin.

The purpose of this note is not so much to present experimental results as to suggest the use of color-charts in spectrophotometric measurements of certain natural phenomena. Such charts offer a quick and simple means of making observations under conditions where the use of elaborate spectrophotometric apparatus is impracticable. Many instruments involving the use of the color-charts (or suitably prepared colored transmission-wedges) can readily be devised for any particular problem.

The following method of the measurement of visibility at sea is suggested. The relative brightness difference between the sea and sky near the horizon is the greatest in clear weather and the least in fog. Therefore, a measurement of the difference in brightness between the sea and the sky near the horizon may yield a value which may be a function of the visibility, and which may provide a means of measuring the visibility. Further investigation of this method is under way.

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CYCLICAL VARIATIONS IN PRECIPITATION, RUNOFF, AND LAKE-LEVELS AND THEIR RELATION TO LONG-RANGE FORECASTING

A. F. Gorton

The idea that droughts, floods, severe winters, and other eccentricities of the weather recur at more or less definite intervals was quite widespread even in ancient times as shown by biblical chronicles, the writings of the Egyptians, etc. Consequently weather "cycles" are not at all new, but their existence, at least up to the present time, has been denied by the professional meteorologists. In recent years, however, certain interests such as the Power Companies have turned their attention to the possibility of forecasting seasonal precipitation by means of cycles as well as other methods. Furthermore, huge water-storage projects such as Boulder Dam have occupied the limelight and these have placed increasing emphasis on the possibility of forecasting by means of cycles. Indeed, in certain sections of the country such as the great Southwest, the problem of supplying water and electric power to the rapidly growing cities and the difficulty of meeting the irrigation-requirements of the agricultural districts have made it necessary to plan for the probable consumption of ten or twenty years ahead. With regard to the Boulder Dam project, it is quite easy to see that, although the average flow of the Colorado River (as well as the maximum and minimum runoff) are known, it is quite essential to be in a position to estimate with some exactness the probable runoff of the River during the next ten or twenty years, since a miscalculation on this score would result in the height of the Dam being either too great or too small--that is, for efficient power-production and for flood-water control.

What is known of the weather of past centuries lends color to the claim that the cycles have reality. It is of course true that no accurate (quantitative) record of precipitation and temperature could be kept prior to the introduction of the thermometer and the rain-gage; generally speaking, only the eccentricities of the seasons could be noted. For this reason, what little mention is made of the weather is confined to descriptions of disasters, such as floods, droughts, severe winters, prolonged freezing of harbors, rivers, lakes, and seas, and the devastation wrought by hot, dry summers. Such a record makes it possible to extend climatic history in a qualitative way several thousand years into the past, but it is not, of course, of any great scientific value. However, it is clear that there is some regularity to

such extremes of weather and it is from such data, as well as from the record of years of exceptionally good and bad wine-production, that Bruckner deduced his cycle of 32 years. This cycle, by the way, has been detected in records of rainfall, riverflow, and lake-levels during recent years.

Coupled with this history of recurring anomalies of the weather, we have vague but persistent evidence of a gradual drying-up or desiccation of climate in certain regions, such as Mongolia, Tibet, Iraq, northern Africa, Peru, Mexico, and in our own country in New Mexico (site of the cliff-dwellers); in most cases the evidence of desiccation is based on lowered lake-levels, as shown by older strand-lines, terraced beaches, and roads along the shore at much higher elevations than the present roads. Evidence based on remains of former civilization is fairly conclusive, too, because the present water-supply of such regions is decidedly below the minimum required for human habitation.

As far as forecasting is concerned, such changes, if real, are not of much assistance, unless it can be shown that they are related to such a thing as changes in solar activity. However, they involve cycles of several hundred years or more at the least.

In any study of rainfall-data, length of record covered by the observations is of paramount importance. Unless a sufficient period of time has elapsed, it may be impossible to establish a reliable mean or normal. Consideration of the older records, such as those of Charleston, Boston, Rome, and Padua points to the existence of long swings or cycles covering 70 to 90 years or more. It is, therefore, important in considering rainfall-records on the west coast to compare the data for the station in question with that for Sacramento, San Francisco, or San Diego, each of which now has an 80-year record, or even with an eastern station such as Boston or Charleston.

It is possible to establish the existence of certain cycles by means of official weather-bureau records of rainfall and temperature, although in no case are they older than 60 years. For some stations it is legitimate to extend the record by means of unofficial sources, since fairly accurate observations have been made in the older cities of the east since revolutionary times. As regards rainfall, a trustworthy analysis requires the grouping of a number of stations, and the averaging of the records, but the latter must be homogeneous, that is, consistent among themselves. In California, for example, significant districts may be chosen in northwestern, central, and southern California, but stations in one major area must not be grouped with those in another.

Owing to the essentially fortuitous nature of the seasonal (annual) figures at any one station or region, the straight plot of the precipitation, or even the curve of five-year means, is likely to show no regular periodicity. Similarly, a plot of the annual means of the sunspot-numbers shows nothing beyond the eleven-year or elementary cycle. A more searching analysis is required to reveal the other cycles, and the first step is to "smooth" the curves by suppressing the shorter oscillations. The curve of accumulated departures from the normal, or "mass" curve, which is simply the first integral of the observed values, is, however, only one way of "smoothing," that is, suppressing the shorter variations and emphasizing the longer cycles. Other methods include lustrum (five-year) or decade-means, "running" or overlapping five-year, ten-year, etc., means, and the more elaborate types of summational analyses such as those of Clough and Streiff (H. W. Clough, Mon. Weath. Rev., v. 56, 251, 1928, and A. Streiff, Mon. Weath. Rev., v. 54, 289, 1926). Application of these methods to California precipitation-records shows that fluctuations of rainfall occur at intervals of 2-3 years, 5-6 years, and 22-26 years, the first being more noticeable in records of northern stations and the second in southern California. Precipitation at Los Angeles shows successive wet- and dry-periods, 11 years in length, the total cycle of approximately 22 years being the Bruckner cycle; in addition to these, there is evidence of a longer or secular cycle of 55-60 years. Probably the most important one for forecasting purposes is the 5 1/2-year cycle, especially in southern California. The last is especially marked in records of southern California stations; it is, moreover, brought out by computing the frequency of occurrence of seasons with two or more consecutive months of decidedly abnormal rain--the San Diego record containing thirteen such seasons in 72 years.

All of these cycles are deducible from the record of sunspot-numbers, also from the stream-flow and runoff of storage-basins in various parts of the country. Scientists are not agreed as to the nature of the connection between sunspots and the weather, but it is only fair to say that there is a growing body of evidence as to a causal relation between the two. In the eastern part of the country, records show that violent storms are frequent when sunspots are numerous.

The recent work of Streiff points to interesting relations between characteristics of rainfall and stream-flow in different parts of the globe and between cycles brought out in these elements and those deducible from the sunspot-numbers ($W_o$lf). Thus, rainfall-records from both the east and west coasts of this country show the Brückner cycle, but displaced in phase by 180°. On the east coast the "residual" curve of Wolf numbers is in phase with the rainfall, on the west coast it is out of step with the rain. The Murray River in Australia shows the same (Brückner) cycle, there being a six-year lag between southern Australia and southern California. In this country, the Huron River, the Penobscot River, and others all show the 11-year cycle, in addition to shorter cycles, one of which Clough claims to have discovered in the sunspot-curve, as well as in records of temperature and terrestrial magnetism.

In spite of the perplexity in the minds of many investigators regarding the reality of cycles in meteorological as well as solar phenomena, there is a twofold reason for dwelling on the importance of establishing such cycles, if it can be done in a sound, scientific fashion. In the first place, they will aid in placing meteorology on a dynamical basis, since thermal changes will be traced to variations in the solar output (cycles in pressure have already been connected with solar changes). Since the ocean-surface is much more important than the land as regards receipt of the energy from the Sun, it is correspondingly more important as a source of back-radiation to the atmosphere. Consequently, the output of heat from the ocean-surface (involving surface-temperature, vertical temperature-gradient, and circulation in the upper 50 meters at least) will be sought as an explanation of major changes in the seasonal weather of the continents. In the second place, it will be possible to make forecasts of the trend of precipitation over periods of 6, 11, and even 25 years. The value of such predictions to agricultural, economic, and financial interest, not to mention the large utility companies, could hardly be overestimated.

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AMERICAN GEOPHYSICAL UNION

Twelfth Annual Meeting

REPORTS AND PAPERS

SECTION OF TERRESTRIAL MAGNETISM AND ELECTRICITY

Washington, D. C.
April 30, 1931

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MAGNETIC WORK OF THE UNITED STATES COAST AND GEODETIC SURVEY, 1930-31

D. L. Hazard

Magnetic surveys--The field-work in terrestrial magnetism in recent years has been devoted primarily to the occupation of repeat-stations all over the country at intervals of about five years to determine the change of the Earth's magnetism with lapse of time. With the end of 1930 sufficient data had been secured to extend the secular-change tables to 1930 and prepare an isogonic chart for that year.

The use of an automobile as means of transportation has materially facilitated the work in the field. It has also made possible, without much loss of time, the inspection of old stations and the occasional replacement of stations no longer available along the route of travel between repeat-stations. Where it was formerly necessary to consider convenient railroad-connections in deciding on the sequence of stations in a season's work, it is now good highways between stations that are important.

When the systematic magnetic survey of the country was begun in 1899, it was planned to place a marked station at every county-seat. It was expected that many of them would be used by local surveyors and engineers in testing their compasses, and accessibility was given much weight in the selection of station-sites. The grounds about the court-house or the grounds of a public school frequently afforded a suitable location within the city limits. With the growth of urban population and the accompanying spreading out of towns and cities, the old stations are being rendered useless at an increasing rate. At the same time the almost universal use of automobiles has made a point 20 miles away as accessible today as was one two miles away 30 years ago. Accordingly stress must now be laid on future availability and less on accessibility in the location of magnetic stations, particularly those intended for use as repeat-stations.

With the rapid development of the triangulation-work of the Coast and Geodetic Survey contemplated by the Temple Act and made possible by a recent increase of appropriation, it is expected that within 12 years there will be a first- or second-order triangulation-station within 25 miles of any point in the country. For each of these stations the latitude and longitude and azimuths to adjacent stations will be computed with accuracy. At each station the true bearings of a number of well-defined prominent objects will be determined also, as an aid to the orientation of local surveys. Many of these stations will be suitably located for use as magnetic stations, with good prospect of future availability. Their use will simplify the work of the magnetic observer, since solar observations for azimuth and position will not be needed.

Declination-observations with compass-declinometer at triangulation-stations are a regular part of the observing programs of the ships doing most of the survey-work in Alaska, Hawaii, and the Philippine Islands. These are supplemented by observations at selected repeat-stations at intervals of about ten years.

Observatories--Magnetic observatories of the Coast and Geodetic Survey have been in operation as follows: At Cheltenham, Maryland, since 1901; at Sitka, Alaska, and Ewa, near Honolulu, Hawaii, since 1902; near Tucson, Arizona, since 1910; and near San Juan, Porto Rico, since 1926 (replacing the one at Vieques, Porto Rico, 1903-1924).

Steady progress is being made in improving their instrumental equipment to secure greater accuracy, efficiency, and dependability. A new recording-apparatus has been developed, with gravity-drive and electric lamp. Hourly time-marks are controlled by a pendulum-clock and radio time-signals. The horizontal-intensity and vertical-intensity variometers at the Cheltenham, San Juan, and Tucson observatories are now equipped for temperature-compensation, and variometers so equipped are ready for shipment to Sitka. In the vertical-intensity variometer, provision has been made for a reserve spot, an important feature at Sitka, where the amplitude of magnetic disturbance is so great.

At all of the observatories deflections for the determination of H- and Z- scale-values are now made at a single distance great enough (225-300 cm) to render the distribution-effect negligible, at the same time eliminating the danger of disturbing the variometer when manipulating a deflector supported on a bar attached to it. Supports for the deflector are fixed at equal distances north (or south) of the three variometers, usually outside of the instrument-room so that the deflections may be made without entering the room.

With special reading-scales and a preliminary adjustment of the base-line values it is now possible to read directly from the magnetogram absolute hourly values which as a rule require only occasional minor corrections when the final base-line adjustment is made, except in the case of a variometer not compensated for temperature, where the temperature-correction must be applied.

With the cooperation of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington it has been possible to provide for atmospheric-electric observations at the Tucson Observatory, and since October 1929 continuous photographic records have been secured of the variations of conductivity and potential gradient.

Because of its interest in the study of earth-currents, the American Telegraph and Telephone Company has arranged to have placed at the disposal of the Coast and Geodetic Survey two long-distance telephone-lines of the Mountain States Telegraph and Telephone Company extending approximately north and east from Tucson. The necessary instruments and equipment for measuring earth-currents are being provided and installed by the Department of Terrestrial Magnetism and they will be operated by the observers at the Tucson Magnetic Observatory.

There is a steadily growing demand for prompt information regarding magnetic disturbances. This has been met in part by telegrams from the Tucson Observatory reporting the beginning and end of magnetic storms. Only a limited number can be reached in this way, however. A much broader distribution of this and similar information was made possible by the inauguration of Cosmic Data Broadcasts in August 1930 by the American Section of the International Scientific Radio Union in cooperation with "Science Service." The magnetic character of the 24-hour period ending at 7 a.m., 105th meridian standard time, is furnished daily by the Tucson Observatory and sent out by radio from Washington the same afternoon.

Publications--With the limited personnel available in the past, little could be done beyond the routine work of preparing the field- and observatory-results for publication in convenient form for those wishing to make use of the data. The results of the field-observations are published annually; collected results in the form of magnetic tables and charts are published at intervals of about ten years. Publications on the magnetic declination in the United States, intended especially for the use of local surveyors and engineers, are gotten out at five-year intervals. A series of publications is being issued giving information about the declination in individual states or small groups of states.

The observatory-results have been published up to the end of 1924 and the preparation for publication of the 1925 and 1926 results is well advanced. For subsequent years the tedious and time-consuming routine work of conversion to absolute values will be very much reduced, since the direct scaling of absolute values at the observatories began in 1926. With the increase in personnel becoming available in July 1931, it will be possible to cut down rapidly the amount of arrears in the publication of observatory-results, but there is no immediate prospect of opportunity to make use of this extremely valuable mass of data in the study of the many problems awaiting solution in the field of terrestrial magnetism.

Among the recent publications may be mentioned:

United States magnetic tables and magnetic charts for 1925, published in 1929. This contains the results of the magnetic survey of the United States, with corresponding values for January 1, 1925, and the secular-change tables used in deriving them, and maps showing lines of equal magnetic declination, dip, horizontal intensity, and vertical intensity.

Directions for magnetic measurements, third edition, 1930. A general revision was made to bring it up-to-date, including some changes suggested by the Department of Terrestrial Magnetism to render it more serviceable for magnetic observers outside the United States.

Distribution-coefficients of magnets, by George Hartnell, 1930. This is a new development of the formulas representing the interaction of two magnets, one suspended and the other deflecting, and their application to the special cases usually encountered in magnetic work. A number of important relations are brought out.

Magnetic declination in Delaware, Maryland, Virginia, West Virginia, Kentucky, and Tennessee.

Publications in preparation, which it is expected will be ready for issue before the end of the year 1931 are: Alaska magnetic tables and magnetic charts for 1930; Magnetic declination in the United States in 1930; Magnetic declination in South Carolina, Georgia, Alabama, Mississippi, and Louisiana; Results of magnetic observations made by the United States Coast and Geodetic Survey in 1930; Results at the Cheltenham, Honolulu, and Sitka magnetic observatories for 1925 and 1926.

U. S. Coast and Geodetic Survey,
Washington, D. C.

FIELD- AND LABORATORY-INVESTIGATIONS OF THE CARNEGIE INSTITUTION OF WASHINGTON

J. A. Fleming

Laboratory investigations

Magnetic disturbances and diurnal variation--The application by Peters of stereographic projection in the analysis of magnetic disturbances and their relations to solar conditions was continued as regards directions in space and geographical distribution of the initial changes in the Earth's magnetic field, indicated by photographic records at 25 observatories for the magnetic storm September 21, 1925. Apparently the changes in the Earth's field represented by the individual details at the beginning of the storm depend to some extent upon local regional conditions. Magnetic storms of January 29 and March 29, 1924, March 5, 1926, January 24 and May 27, 1927, and October 18, 1928, are being studied by this method.

Investigations were made by Wallis of the geographical distribution of magnetic disturbances recorded at Bowdoin Harbor and at seven well-distributed observatories for March 14, 1922, and also for January 29, 1924, as recorded at the Refuge Harbor and at nine other well-distributed observatories. In both cases the zone of maximum auroral frequency was the region of most intense magnetic activity; sharp drops were shown in both auroral frequency and magnetic activity after passing this zone southward with a comparatively low level of magnetic activity in temperate and tropical latitudes except for a slight rise in the region of the magnetic equator. Wallis' examination of the diurnal variations at Arctic stations as affected by magnetic disturbances indicates that in declination there is usually a conversion of a double diurnal-variation wave into a single wave with greatly exaggerated amplitude, while in horizontal intensity and vertical intensity the ordinary diurnal-wave of a normal day is retained in form but is more exaggerated in amplitude.

Further study made by Fisk of the interrelations between solar activity and magnetic secular-variation or rate of annual change shows an apparent lag between solar activity as measured by sunspot-numbers and magnetic activities as indicated by magnetic character-numbers. The difference between annual changes as derived from all-day means and from selected-day means based upon discussion of the data at Cheltenham fluctuates in agreement with sunspot-numbers and there appears to be the same sort of lag as that indicated by magnetic character-numbers.

Suitable methods and formula for an effective measure of magnetic activity are under way by Duvall. An ordinate-integrator was designed by Huff and constructed in the Department's instrument-shop, and preliminary results using magnetograms from the

Huancayo, Watheroo, and Cheltenham observatories show excellent correlation-factor as well as an unexpectedly close correlation when measuring hourly activities. This method offers an advantage since that variation inevitable in personal judgment is eliminated. Values obtained are further in good agreement with other more laboricus mathematical measures of activity, as well as those obtained using international character-numbers. Investigation of storm vector-changes and field energy-changes gives concurrent results in general.

Magnetic secular-variation--Continued investigations by Fisk of secular variation confirm their great importance in theoretical problems involving changes in the Earth's field and show important conditions governing isoporic movements. The complexity of the secular-variation phenomenon is made more apparent by these investigations, and the importance of its bearing upon the study of physical conditions and movements within the Earth too deep for penetration by other methods is emphasized. Compilations were prepared by Johnston of secular variations over the oceans made possible by the recent cruise of the Carnegie, and the final discussion of all data obtained at sea by the Department since the inauguration of the oceanic survey in 1905 is in progress. These indicate the importance and necessity of the continued accumulation and investigation of such data.

Atmospheric electricity--The discussion by Gish and Wait of the continuous registration of air-potentials and air-conductivity obtained aboard the Carnegie brings out more vividly than the eye-readings obtained heretofore the advantages of atmospheric-electric observations at sea, especially for studies of world-wide and cosmic effects. Among these is the confirmation of the universal-time phenomenon in the diurnal variation of the electric potential of the air.

The discussion by Wait of continuous atmospheric potential-gradient records during August 1929, with careful control of insulation-leak and atmospheric pollution, at a temporary station near the geographical center of the United States at Penalosa, Kansas, shows diurnal variation in close agreement for Greenwich mean time with that obtained from observations at sea by the Carnegie in the month of August during her various cruises.

A detailed atmospheric-electric survey by Johnston and Wait in the District of Columbia and neighboring region in Maryland indicates this to be a region of atmospheric-electric anomaly with low conducting area in the District. For computing true values of air-earth current the importance of establishing stations where there are undisturbed equipotential surfaces was indicated as well as the necessity of installing potential-gradient and conductivity-apparatus at similar heights above the ground and sufficiently near each other.

Intercomparisons by Gish of penetrating-radiation apparatus, two of the Kolhörster type and one of the Department's type, show, despite definite tendency for variations common to all three instruments, considerable changes characteristic of the individual instruments. Further investigations of this matter must be made before such measurements may be placed on an entirely satisfactory basis.

Experimental observations by Tuve, Hafstad, and Dahl of the penetrating-radiation by the method of multiple coincidences of Geiger-Müller tube-counters have been made during the past year and a half. The variation with zenith-angle of intensity of the hard components (measured in the sub-basement under four feet of earth and concrete) shows a maximum at the zenith as expected. Measurements for two months on a narrow band parallel to the Milky Way show no sidereal-time effect, but these observations must be continued for a year or more to reduce the statistical variation below one-half per cent. Using the line of tube-counters as an "ultra-gamma-ray telescope," pointed toward the Sun during two separate hourly periods daily, the one-half per cent solar component of the hard rays announced by Hess in December 1930 has not been confirmed, although the observations to date would not detect a solar component much under this figure. Observations are in progress which should detect with certainty a solar component considerably smaller than one-half per cent.

A promising investigation by Wait and Torreson is that of the condensation-nuclei and the correlation of the concentration of these nuclei in the atmosphere and of certain meteorological elements with those of electric potential-gradient and electric

conductivity of the atmosphere. The mechanisms responsible for local features of diurnal variation of potential gradient considered include space-charge and convection currents. Apparatus is now being installed for the study of atmospheric pollution in relation to the electrical carriers in the air. A closed air-flow tube is provided in which the kind and amount of pollution in the air can be regulated and the temperature and humidity of the confined air kept under control. Instruments for measuring the number of large ions, small ions, Owens particles, and Aitken nuclei will be connected into the air-flow circuit to study (1) the effect of different kinds and quantities of pollution upon the electrical carriers in the atmosphere, (2) the relation of the number of small and large ions to the total number of Aitken nuclei, (3) the relation between Owens particles and Aitken nuclei, and (4) the effectiveness of existing instruments in measuring the number of those pollution-particles which most affect the number of electrical carriers in the atmosphere.

Earth-currents--Discussion by Gish and Rooney of the earth-current data for three years, 1927-29, at the Huancayo Magnetic Observatory indicates the mean diurnal-range of the northward component 2.83 mv per km with maximum at 9^h and minimum at 15^h (75° west meridian time) with relatively small amplitudes during the hours of darkness. The same is shown for the component at right-angles (values being considered positive for current flowing eastward) except that the mean range is higher, 3.26 mv per km. The direction of current is northwestward from 2^h5 to 12^h5 and southeastward for the remainder of the 24 hours. Contrary to results at Berlin, Ebro, and Watheroo, the times of daily maximum and minimum are practically constant throughout the year. The mean diurnal-range changes with season and is in general agreement with the results at the other three stations, the principal maximum occurring in June and the minimum in March and October. Disturbance-variations of relatively short and irregular period with amplitudes considerably greater, on the average, than those of diurnal variation predominate during the daylight hours.

Auroras--Discussion by Davies of the aurora recorded at Little America, well inside the belt of maximum auroral activity, during March to September 1929 shows majority of displays seen in the east and displays seen on over 1,400 half-hourly occasions--48 per cent of the number on which cloud- and light-conditions permitted them being seen. A progressive change in displays was noted throughout the period of darkness in the following: (a) Average intensity greatest in April, decreasing to a minimum in September; (b) ratio of number seen to the number that could possibly have been seen greatest in April, decreasing to a minimum in September; (c) average altitude least in April and greatest in September, increasing slightly through the period; (d) proportion exhibiting ray-structure increased markedly in September. A period of 27 to 28 days was evidenced, as also a short period of about four days. The majority of displays seen were of weak intensity.

Improvements to effect more economical compilations of data for discussion--An important advance in the more economical compilation of photographic records is the development by Peters and Green of a photographic method to reduce the ratio of ordinate- to abscissa-scale. As this method makes possible photographic reproduction on like scales of any day's record at many observatories, photographic composites and means may be readily made, features of magnetic disturbances may be readily compared and correlated, and thus the time required in laborious reduction and compilation by methods previously used may be materially reduced. Mechanical means for harmonic analyses, essential to investigate periodicities and yet so time-consuming in the use of the older computational methods, are also needed.

Upper-air research--The investigation of upper-air currents through discussion by Bartels of magnetic diurnal-variations at the Watheroo, Huancayo, and other magnetic observatories is in progress. Further experimental approach in this subject is being undertaken in the design of automatic registering instruments for the rocket-method of exploring the high atmosphere.

Atomic physics--Satisfactory progress has been made by Breit in the extension of theoretical investigations in atomic physics.

Experiments by Tuve, Hafstad, and Dahl applying high Tesla voltages to vacuum-tubes have been continued, looking toward the artificial production of rays and radiations of radioactive energies and even higher, for investigating the innermost struc-

ture of matter--the atomic nucleus--and other fundamental problems of electricity and magnetism. The shattering and puncturing of the glass of vacuum-tubes at high voltages caused by powerful electric surges occurring when a tube flashes have been overcome and a practical design obtained to operate reliably at potentials up to 2,000,000 volts produced by Tesla coils. The indications are that the design of tube used can be extended without fundamental changes to operate on higher voltages. Artificial beta- and gamma-rays covering nearly the whole of the radium-spectrum have been produced. The work this winter has been concentrated on the acceleration of protons to radioactive speeds.

Field-work

Observatories--The magnetic, atmospheric-electric, earth-current, and meteorological observations at the Watheroo and Huancayo observatories have been continued by observers-in-charge Parkinson and Ledig and their staffs. The earth-resistivity survey by Rooney in the region of the Huancayo Observatory in Peru shows results typical for an underlying structure of sedimentary rocks and indicates this region to be laterally isotropic. The seasonal variation is small and relatively unimportant. An earth-resistivity survey by Rooney is nearly completed in the neighborhood of the Tucson Magnetic Observatory of the United States Coast and Geodetic Survey in connection with the arrangements made there for earth-current observations through cooperation of the Mountain States Telephone and Telegraph Company, the American Telephone and Telegraph Company, the United States Coast and Geodetic Survey, and the Department. The atmospheric-electric work being done through the cooperative efforts of the Survey and of the Department at the Tucson Magnetic Observatory have continued through the year and indicate that site to be well suited and relatively free from disturbing local features so often encountered at land stations.

Active cooperation was continued with the Apia Observatory to insure the continuation of the magnetic and electric programs there as well as at the Christchurch Observatory in New Zealand.

In the investigations of correlations of magnetic and electric activities with solar activities in cooperation with the Mount Wilson Observatory, spectroheliioscopes are being installed at the Watheroo and Huancayo observatories.

Equipment is being made for installation at Huancayo and Tucson and for a polar station to record, on a rapid time-scale, variations in the Earth's vertical intensity using the large surface-coil method developed by Crichton Mitchell at Eskdalemuir.

The photographic observations of reflections of radio waves from the Kennelly-Heaviside layer increasingly evidence the fundamental importance in terrestrial magnetism of this method of investigating the upper atmosphere. Further possibilities of such research were provided by installing at the Watheroo Magnetic Observatory a short-wave radio station for the study of the planeof polarization of incoming short waves and of interrelation of short waves with magnetic and atmospheric-electric elements. At Watheroo also a static recorder is being operated cooperatively with the Radio Research Board of the Council for Scientific and Industrial Research in Australia. A grant was obtained and plans were made to equip the Huancayo Magnetic Observatory as a sending and receiving radio station suitable for similar experimental work.

Cooperation--The policy of cooperating with other investigators and organizations interested in terrestrial magnetism and electricity has been maintained and helpful contacts established which have contributed at least to the marked increase in geophysical activities, including particularly the increase of secular-variation material so much needed from all parts of the world for theoretical studies.

Plans were made for cooperation with the Wilkins-Ellsworth Trans-Arctic Submarine Expedition on the Nautilus to leave from Bergen, Norway, about the end of June, which it is expected will be completed by August or September. The opportunity offered for securing magnetic data by observations on the ice-floes in the vast unexplored region of the Arctic Basin is unique. The Department has supplied and prepared magnetic equipment for this important undertaking and has assigned Floyd M. Soule of its personnel to the scientific staff which is in charge of that veteran in Arctic geophysical exploration, Dr. H. U. Sverdrup of the Michelson Foundation of Norway.

An active part has been taken in forwarding the plans of the International Commission for the Polar Year 1932-33. It is hoped that favorable action may be taken to permit the occupation of a station near Fairbanks by the United States Coast and Geodetic Survey through Congressional appropriation and to reoccupy Fort Conger through private sources. In cooperation with Science Service, the United States Coast and Geodetic Survey, and the Auroral Observatory at the Alaska Agricultural College and School of Mines, an auroral code was prepared for the daily radiogram of cosmic phenomena of the American Section of the International Union of Radiotelegraphy.

Continued cooperation with the University of Cape Town has given secular-variation data at stations in the Cape of Good Hope, Transvaal, Portuguese East Africa, and Rhodesia. Observer R. E. Gebhardt of the Department is now in Central America and, after occupying stations there, will continue field-work in northern South America. Cooperative arrangements are under way for secular-variation work in China.

Preliminary plans for suitable world distribution of stations through cooperation of various governments and organizations for a definite secular-variation program at suitable intervals have been prepared for consideration by a special committee of the International Union of Geodesy and Geophysics appointed in Stockholm to perfect such a program.

Development of apparatus for field-work--The practical possibility of a submerged ocean-magnetograph for observation at sea is being studied; such apparatus--comparatively inexpensive for non-magnetic construction--could be operated from any vessel. The need for continuity of reliable secular-variation determinations at sea doubtless would be better met by a non-magnetic vessel similar to the Carnegie, but the funds required for construction and maintenance are so great that other less expensive means must be provided if practicable, especially since atmospheric-electric determinations may be made satisfactorily on a vessel of ordinary construction. In this connection the laboratory-research on deviations caused by motion aboard a moving vessel or platform is being extended by Peters with the assistance of Huff in designing the extensive experimental apparatus required.

The experimental work by Soule on the earth-inductor method of measuring the magnetic intensity of the Earth's field for the more accurate development of this method at sea is being continued. Both electromagnetic and magnetic methods are being further developed having in mind use not only on surface vessels but on lighter-than-air and sub-surface carriers.

Publications

Observatory--The manuscript for the volume of magnetic results during 12 years from 1919 to 1930 at the Watheroo Magnetic Observatory is nearly completed. In addition to the tabular data for each of the three elements for every hour during this period, the diurnal variations in all elements and components are tabulated and graphed, and analyses made for the five international quiet days and for all days in their means for each month and for each year of the series.

Instrument--A detailed description of the Department's design of atmospheric conductivity recording-apparatus was completed by Torreson.

Polar charts--The compilation by Peters of polar magnetic data for polar regions was continued, and preliminary isomagnetic charts of the Arctic for declination, inclination, total intensity, and horizontal intensity were prepared by Fisk.

The more important papers published in the past year are listed in the following section.

Papers published

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Fisk, H. W. Isopors and isoporic movements. Rep. and Comm., Stockholm Assembly, Internat. Geod. and Geophys. Union, Sec. Terr. Mag. and Electr., Aug., 1930, 23-30 (June 30, 1930).

-----, and J. A. Fleming. On the distribution of permanent repeat-stations. Rep. and Comm., Stockholm Assembly, Internat. Geod. and Geophys. Union, Sec. Terr. Mag. and Electr., Aug., 1930, 31-36 (June 30, 1930).

Fleming, J. A. Report on the work done since the Prague Assembly. Rep. and Comm., Stockholm Assembly, Internat. Geod. and Geophys. Union, Sec. Terr. Mag. and Electr., Aug., 1930, 5-18 (June 30, 1930).

-----. Observations of terrestrial magnetism and atmospheric electricity on last cruise of the Carnegie. Rep. and Comm., Stockholm Assembly, Internat. Geod. and Geophys. Union, Sec. Terr. Mag. and Electr., Aug., 1930, 19-22 (June 30, 1930).

-----. Latest annual values of the magnetic elements at observatories. Terr. Mag., vol. 35, 165-177 (Sept. 1930).

-----. Preliminary report on terrestrial magnetism and electricity at the Stockholm meeting. Terr. Mag., vol. 35,209-212 (Dec. 1930).

-----. Summary of the year's work, Department of Terrestrial Magnetism, Carnegie Institution of Washington. Terr. Mag., vol. 35,231-236 (Dec. 1930).

-----. International Geodetic and Geophysical Union. Standards Year Book 1931, Dept. Comm., Bur. Stan. Misc. Pub. No. 119, 54-60 (1931).

-----. American Geophysical Union. Standards Year Book 1931, Dept. Comm., Bur. Stan. Misc. Pub. No. 119, 60-63 (1931).

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-----. The natural electric currents in the Earth's crust. Sci. Mon., vol. 32, 5-21 (1931).

-----, and W. J. Rooney. Results of earth-current observations at Huancayo Magnetic Observatory, 1927-1929. Terr. Mag., vol. 35, 213-224 (Dec. 1930).

Harradon, H. D. List of recent publications (terrestrial and cosmical magnetism, terrestrial and cosmical electricity, miscellaneous). Terr. Mag., vol. 35, 110, 120-124 (June 1930); 186-192 (Sept. 1930); 264-268 (Dec. 1930); vol. 36, 71-75 (Mar. 1931).

-----. Some notes regarding auroral displays during the months of August and September, 1930. Terr. Mag., vol. 36, 58-61 (Mar. 1931).

Huff, C. Ordinate-change integrator. Rep. and Comm., Stockholm Assembly, Internat. Geod. and Geophys. Union, Sec. Terr. Mag. and Electr., Aug., 1930, 58-60 (June 30, 1930).

Johnston, H. F. Preliminary values of the annual changes of the magnetic elements in the Pacific Ocean as determined from the Carnegie results, 1909-1929, and the Galilee results, 1905-1908. Terr. Mag., vol. 35, 157-160 (Sept. 1930).

-----, and G. R. Wait. Atmospheric-electric survey in the vicinity of Washington, D. C. Terr. Mag., vol. 36, 33-40 (Mar. 1931).

Parkinson, W. C., and O. W. Torreson. The diurnal variation of the electrical potential of the atmosphere over the oceans. Rep. and Comm., Stockholm Assembly, Internat. Geod. and Geophys. Union, Sec. Terr. Mag. and Electr., Aug., 1930, 65-68 (June 30, 1930).

Peters, W. J. Investigation of some individual changes in magnetic elements during a magnetic storm. Rep. and Comm., Stockholm Assembly, Internat. Geod. and Geophys. Union, Sec. Terr. Mag. and Electr., Aug., 1930, 51-55 (June 30, 1930).

Rooney, W. J. The use of resistivity-measurements in the detection of mineralized areas. Rep. and Comm., Stockholm Assembly, Internat. Geod. and Geophys. Union, Sec. Terr. Mag. and Electr., Aug., 1930, 74-75 (June 30, 1930).

-----, and O. H. Gish. Earth-resistivity survey at Huancayo, Peru. Terr. Mag., vol. 35, 61-72 (June 1930).

Wait, G. R. Diurnal variation of the atmospheric potential-gradient at Penalosa, Kansas. Terr. Mag., vol. 35, 137-144 (Sept. 1930).

Wallis, W. F. A comparison of magnetic disturbances at different stations. Terr. Mag., vol. 35, 93-101 (June 1930).

-----. The geographical distribution of magnetic disturbance. Terr. Mag., vol. 36, 15-22 (Mar. 1931).

Westland, C. J. The effect of the sunspot-cycle on the magnetic diurnal variation at Apia. Terr. Mag., vol. 36, 6-8 (Mar. 1931).

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RECENT DEVELOPMENTS IN RADIO-TRANSMISSION MEASUREMENTS

G. W. Kenrick and G. W. Pickard

During the past year investigations have been continued at Boston, Massachusetts, with a view to securing and utilising data giving an insight into the mechanism of radio transmission. In papers to be presented at the URSI meeting on May 1, 1931, Pickard describes an interesting correlation obtained by the use of the data which has already accumulated and Kenrick presents some of the apparatus-development and experimental results evolved during the past year. These results are therefore not presented in detail in this report but a brief outline of projects now at hand and the results obtained follows. A brief discussion of what we conceive to be some of the present problems of radio transmission-theory, the relation of the present observations to the general problem, and the means which should be employed to affect a solution is also included.

Fig. 1--Apparatus for recording field-strength automatically at Tufts College, Medford, Massachusetts

The observations now in progress at Boston include continuous records of field intensity on frequencies of 17.8, 770, and 7,415 kilocycles.

The 17.8-kilocycle observations were inaugurated in 1928 at Newton Center, Massachusetts, and are being continued at Tufts College. The apparatus employed in the 17.8-kilocycle recording is shown in Figure 1, its circuit in Figure 2, and a typical record in Figure 3.

This apparatus provides for records to be taken alternately on an antenna and variously oriented loop, thereby permitting polarisation-phenomena as well as field-intensity variations to be studied. A more detailed discussion of this apparatus and the results obtained is to be found in a recent paper presented at the Convention of the Institute of Radio Engineers in Toronto in August 1930 (de Mars, Kenrick, and Pickard, Low-frequency radio transmission, Proc. Inst. Radio Engin., v. 18, 1488-1501, September 1930).

It will be noted that the marked disturbances of the loop "nul" readings during the night indicate marked changes in polarisation during this period. To avoid confusion, the apparatus is designed to provide separate origin-lines for antenna and loop records as indicated in Figure 3.

The 770-kilocycle observations (in the broadcast range) were first started at Newton Center, Massachusetts, in 1926 on a slightly different frequency and initially extended from 9:00 to 10:00 p.m., E.S.T. (The time was limited by the manual monitoring required in the apparatus first employed and, in the early years, by the schedule of the station.

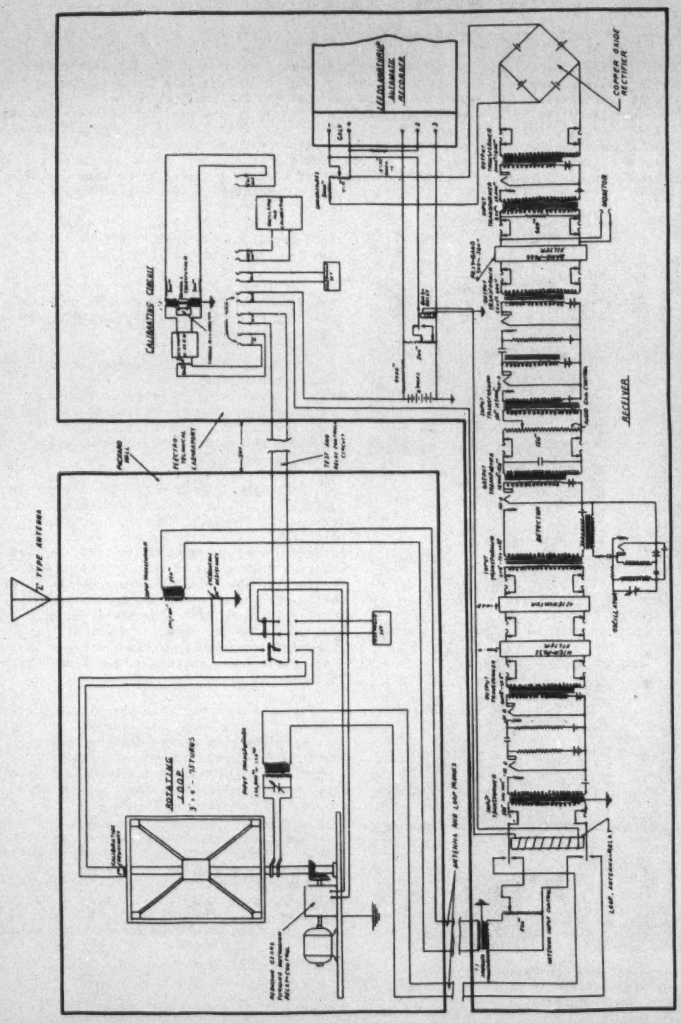


Fig. 2--Schematic diagram of long-wave radio station automatic recording-apparatus at Tufts College, Medford, Massachusetts

During the past year, equipment has been installed at Tufts College which permits a continuous record of field-intensity to be made. This permits the observations to include a longer record on WBBM and also observations on KFAB in Nebraska who shares time with WBBM.

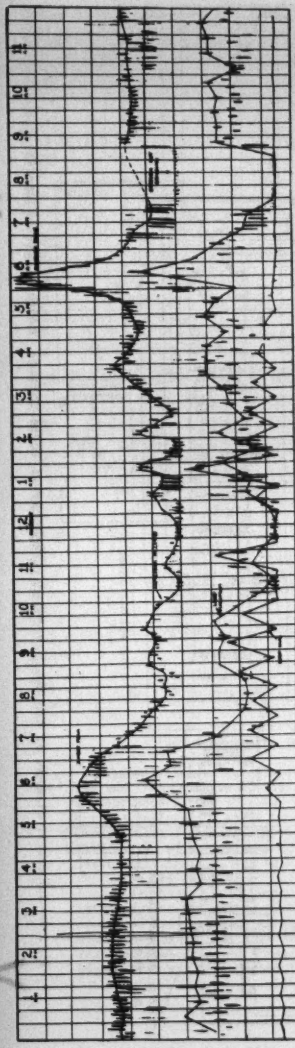


Fig. 5.—Field-intensity from station WCI (17.8 mc) as recorded at Tufts College, Medford, Massachusetts, October 12-13, 1930

The physical assembly of this equipment is similar to that employed in the case of the low-frequency equipment (see Fig. 1). Further development was, however, necessary to provide adequate frequency-stability to permit the use of a low intermediate frequency which was desirable to provide for suitable filtering to eliminate interference from contiguous channels and also to permit the use of a copper oxide rectifier in the output circuit. A wide-range scale which is nearly logarithmic was attained by varying the screen grid-bias on the amplifier-tubes by means of a potentiometer attached to the same shaft as the balancing potentiometer of the Leeds and Northrup recording-potentiometer. A workable range of 50 decibels, that is, an amplitude-range of 300:1, was thus obtained as shown in Figure 5. The circuit-details are shown in Figure 4. (A more complete description of this equipment will soon be available in print.)

During the past year equipment has also been provided for making continuous measurements of field-intensity at higher frequencies. This equipment was made possible by a grant from the Permanent Science Fund, administered by the American Academy of Sciences, and is employed to record the field-intensities in the 7-megacycle region.

While a long enough series of observations have not yet been obtained to render statistical treatment desirable, it is clear that this observation-path is well chosen for the illustration of skip-distance phenomena and is likely to prove quite susceptible to magnetic disturbances.

The equipment employed is similar in general form of assembly and principle to the broadcasting recording-equipment but several new features are made necessary because of the higher frequency. The screen-bias method of securing a nearly logarithmic scale is retained but a higher intermediate frequency is employed. A crystal-oscillator is employed but a fifth harmonic amplifier is used to provide the required beat-frequency. Modulation of the plate-supply of this amplifier permits an audio-frequency output for use with the copper oxide rectifier (see Fig. 6).

The records obtained in many cases show strikingly the phenomena of skip-distance. Thus, during the early months of 1931, station WEO at New Brunswick, New Jersey, was in nearly 24-hour operation. The observed field-intensity recorded at Boston, Massachusetts, during this period, however, is shown in Figure 7. It will be noted that this field rises exceedingly abruptly shortly after sunrise and falls again during the sunset-period. Slightly disturbed transmission conditions, however, profoundly modify the observed fields in this critical skip-distance region. This is illustrated in Figure 8, where

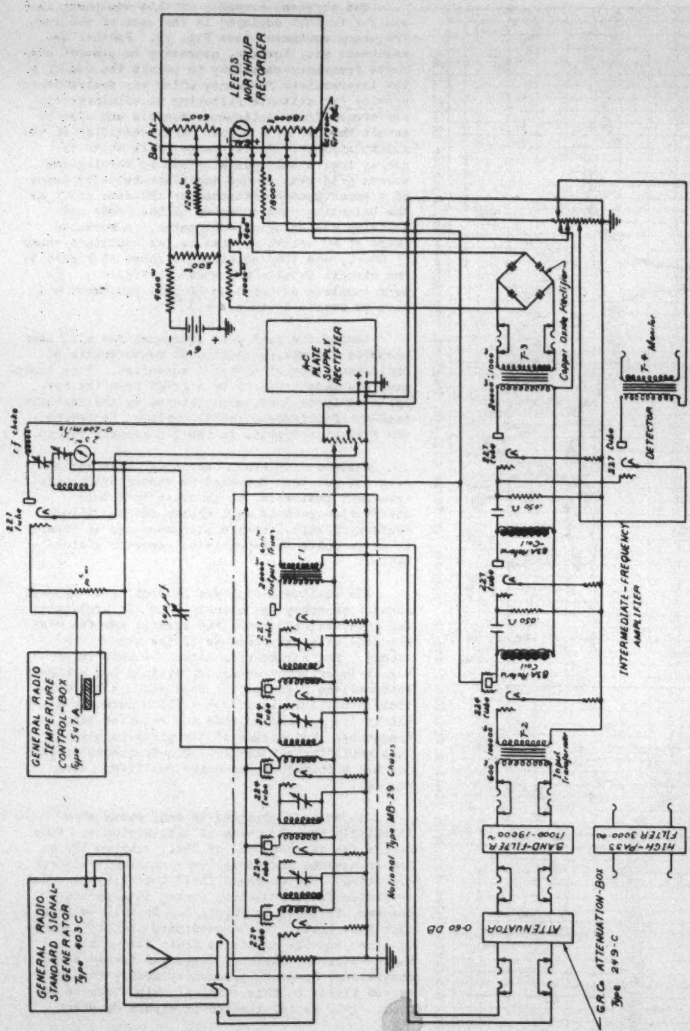


Fig. 4--Schematic diagram of broadcast frequency-recorder at Tufts College, Medford, Massachusetts

it will be noted that the field-intensity did not rise until early afternoon and then was subject to severe disturbance and fading.

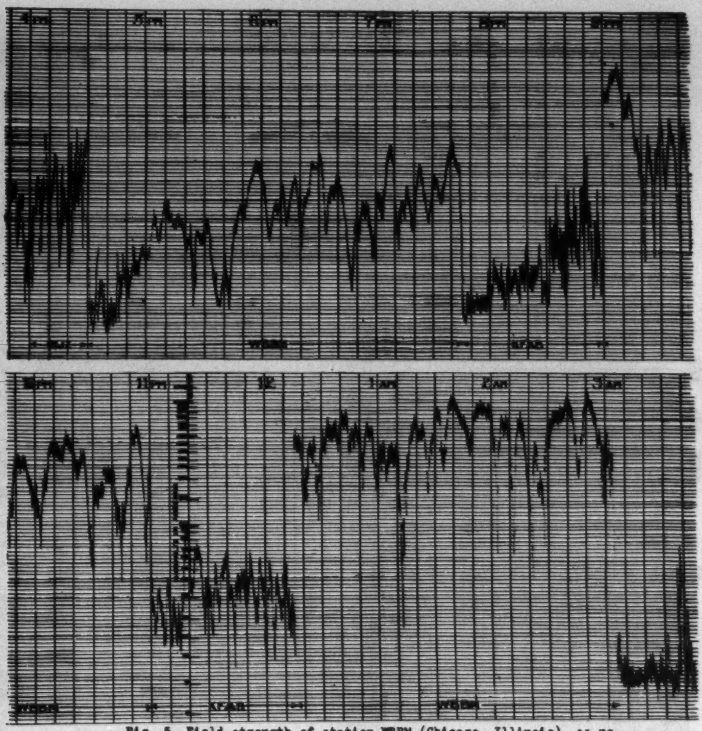


Fig. 5--Field-strength of station WBBM (Chicago, Illinois), as received at Tufts College, Medford, Massachusetts, March 4-5, 1931

In addition to the field-intensity studies, observations have been made during the last few years on the height of the Kennelly-Heaviside layer. Work in this field was extended during the past year and is also being continued; marked advances in the methods employed in these investigations have been made which should soon be ready for presentation. Some of the results of these studies have appeared recently (P. A. de Mars, T. R. Gilliland, and G. E. Kenrick, Kennelly-Heaviside layer studies, Proc. Inst. Radio Eng., v. 19, No. 1, 106-113, 1931). It is of interest in this connection to review the relation of observations of this type to field-intensity studies such as those described. Most commercial and no little scientific interest centers about the intensity and the nature of the received fields. Hence statistical series of the type described are obviously an important part of any comprehensive radio-transmission research-program, for such observations enable us to study the changes associated with cosmical phenomena and through correlations with such elements we are enabled to anticipate what may be expected in the future.

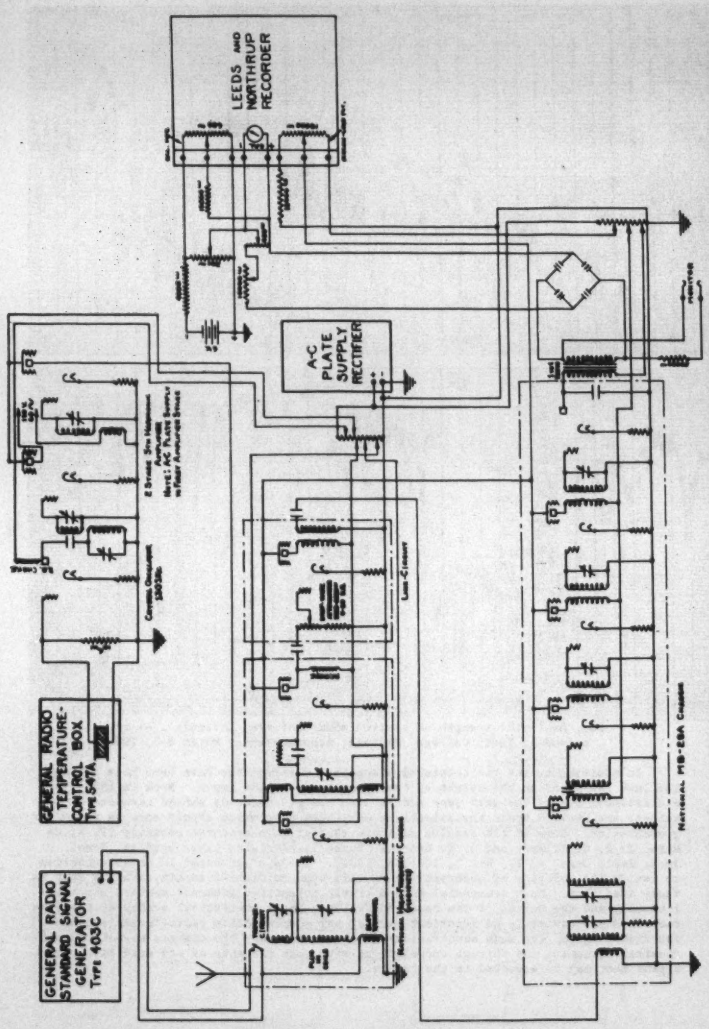

LEEDS AND NORTHRUP RECORDER
A-C PLATE SUPPLY RECTIFIER
GENERAL RADIO TEMPERATURE-CONTROL BOX Type 547A
GENERAL RADIO STANDARD SIGNAL-GENERATOR Type 403C

Fig. 6.--Schematic diagram of high-frequency recorder at Tufts College, Medford, Massachusetts

One of the great problems in field-intensity studies from the standpoint of a general theory appears to be one of sampling, for the most superficial observations in the broadcast-band are sufficient to emphasize that the mean intensity contributed

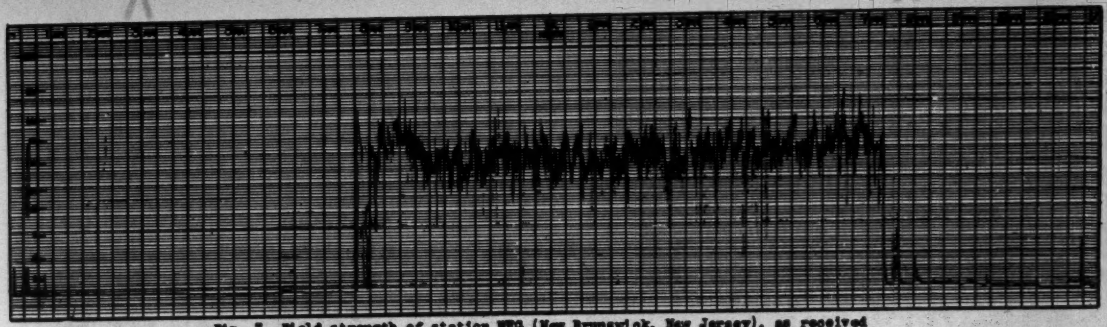


Fig. 7—Field-strength of station WEI (New Brunswick, New Jersey), as received at Tufts College, Medford, Massachusetts, March 17, 1931

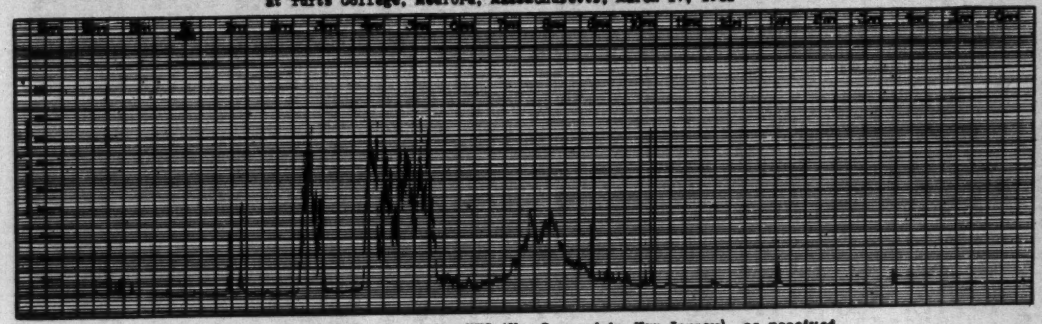


Fig. 8—Field-strength of station WEI (New Brunswick, New Jersey), as received at Tufts College, Medford, Massachusetts, March 25-26, 1931

from sky-wave transmission is conditioned by extremely complicated laws and it is far from safe to assume that an increase in distance will invariably be accompanied by a decrease in mean fields for the same transmitted power and frequency (even when skip-distance phenomena as ordinarily understood do not enter, as in this case).

No measurements of layer-height can supplant, but must rather complement and clarify the field-intensity changes observed; unquestionably they are very valuable when so used. Emphasis in layer-height observations has, however, thus far centered to a considerable extent about observations made at nearly normal distance, that is, over a very limited distance between transmitter and receiver; while such observations will (and in fact have) clarified many of the general phenomena of transmission, it is probable that the mechanism is likely to prove quite variable with path and that observations over transmission-paths more comparable with those where the field-intensities are of interest are likely to prove best adapted to disclose the nature of the rather erratic range-phenomena encountered in practice.

Observations of this type involve new difficulties of technique and in general require the cooperative endeavor of widely separated groups, but it is hoped that facilities will be available which will enable us to soon attack this phase of the problem as well as to continue the types of investigations already described and extend the frequency-ranges observed.

Tufts College,
Medford, Massachusetts

THE URSI COSMIC RADIO BROADCAST

Watson Davis

As a means of prompt distribution of fundamental inconstants of nature, the daily Ursigram is assembled in Washington from messages received from observatories. It is transmitted by radio from the Navy radio station, NAA.

Since the inauguration date, August 1, 1930, these daily Ursigrams have included coded values for the solar constant (furnished by the Smithsonian Institution), magnetic conditions (furnished by United States Coast and Geodetic Survey Magnetic Observatory at Tucson, Arizona), and sunspots (furnished by Mount Wilson Observatory). Plans are now under way for adding to the Ursigrams auroral observations (made by Alaska Agricultural College and School of Mines auroral observatory at College, Alaska) and Kennelly-Heaviside layer-heights in the form of a weekly value in code (to be supplied by the United States Bureau of Standards or Tufts College).

The messages from Mount Wilson and Tucson are transmitted by the Army radio net to Science Service in Washington, D. C., where they are assembled for transmission on a set schedule (at present 5:00 p.m. Eastern Standard Time) on frequencies 12,045 and 4,015) from NAA, United States Navy, Arlington. Science Service also issues each week a mimeographed Science Service Research Announcement containing tabulations in code of the Ursigrams as well as the texts of the French Ursigrams as copied by the United States Navy. The Journal of Terrestrial Magnetism and Atmospheric Electricity (Editor, Jno. A. Fleming, 5241 Broad Branch Road, Washington, D. C.) publishes compilations of the Ursigrams quarterly.

Code explanations and further details are issued by Science Service. Those engaged in research may obtain code details and the weekly summaries of Ursigrams on request without charge by addressing Science Service, Washington, D. C.

Upon the occasion of extraordinary phenomena or other data of interest to the many scientists and communication experts in Europe and North and South America who copy the daily Ursigrams, plain English additions to the Ursigrams are made.

It is hoped that those engaged in making observations of the inconstants of nature will telegraph special observations, predictions, etc., to Science Service, Washington, D. C., for this purpose.

The Ursigram service is a splendid example of scientific cooperation and the utilization of scientific inventions for the purpose of promoting scientific research further. As its usefulness becomes more evident it is hoped that there can be included in the Ursigrams a larger variety of current scientific information which of necessity loses its usefulness if not distributed promptly.

It is just as important to use modern communication-facilities to distribute fundamental information about the fluctuations of important cosmic manifestations as it is to distribute the prices of stocks and bonds promptly to those interested. Weather-information has long been given prompt transmission and the Ursigram service is simply an extension of this fundamental principle.

The Ursigram service is operated under the auspices of the American Section of the International Scientific Radio Union through its committee on cooperation of which Dr. A. E. Kennelly of Harvard, instigator of the Ursigram activities, is chairman. To Dr. Kennelly and the many other scientists whose efforts have brought the Ursigrams into useful existence, those benefiting owe a debt of thanks.

Science Service,
Washington, D. C.

REPORTS OF GEOMAGNETIC AND ELECTRIC WORK OF ORGANIZATIONS AND INDIVIDUAL INVESTIGATORS IN THE UNITED STATES, 1930-31

Harlan W. Fisk

Reports from about twenty individuals and organizations engaged in some phase of geomagnetic or geoelectric investigations have been received in response to the request of the Secretary of the Section. These interesting reports are given in full following these few notes which indicate the general scope of the investigations reported.

Magnetic surveys and observatories--The Carnegie Institution of Washington and the Coast and Geodetic Survey have reported separately on their activities in these fields as they are the principal organizations in the United States compiling data for determining secular variation or obtaining registrations of daily changes in the magnetic and electric elements. Some magnetic observations are obtained by the Hydrographic Office in connection with local surveys, and plans for the investigation of the anomaly in the Gulf of Panama are reported. A magnetograph is operated at Mount Wilson for the study of correlations of magnetic and solar activity. In Canada, the Dominion Observatory reports 47 repeat-stations reoccupied during 1930 as a part of a comprehensive scheme to reoccupy about 200 stations distributed over the entire country. The Topographical Survey of Canada also reports activity especially in the determination of declination, having made 28,000 precise determinations since the beginning of the work in 1880. Many of the stations are marked as "Repeat-stations." Both organizations maintain standard corrections to their instruments by comparison with the standards at the Observatory of the Meteorological Service at Agincourt, and, in addition, a complete intercomparison of the instruments of the Dominion Observatory was made in March 1931 at Washington with the standards of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington.

Isomagnetic charts--The completion of the quinquennial revision of the world charts of isomagnetic lines by the Hydrographic Office utilizing the latest values determined by the Carnegie was reported last year. Mention of the charts prepared and issued by the Coast and Geodetic Survey and of preliminary charts of isomagnetic lines for the Arctic, prepared by the Carnegie Institution, is made separately.

Geomagnetic discussions--Considerable attention has been given by the Carnegie Institution to variations in the rates of secular change, particularly to a possible relation to solar periodicities. The question of magnetic storms has been studied by Wallis and Peters at the Carnegie Institution as reported separately. The effects of magnetic storms on telephone and radio transmission have been under careful study by the Bureau of Standards, the American Telephone and Telegraph Company, and others, and the correlation of solar activity and terrestrial storms is being investigated at Mount Wilson. Wallis finds differences in time of propagation over the Earth for different

storms. The sudden commencements are often recorded simultaneously at all observatories, while other major features during the storm are regional in their effects. Nicholson (Mount Wilson) concludes, after a statistical study, that the importance of the active region being in a central position of the Sun's disk at the time of the magnetic storm has been overestimated. The Bureau of Standards finds that magnetic storms do not affect received radio-wave intensities, but increase atmospheric disturbances. The Bell Telephone Laboratories find that wire-system lines are not affected by magnetic storms but short-wave radio channels operating over the North Atlantic are rendered useless for periods varying from a few hours to a day or two. Hulburt (Naval Research Laboratory) has continued the development of the ultraviolet-light theory of aurorae and magnetic storms. Maris (Naval Research Laboratory) finds confirmation of that theory by a statistical study of storm records since 1839.

Aurorae and zodiacal light--The auroral station at the Alaska Agricultural College and School of Mines near Fairbanks, Alaska, reports that work has been well started. The preliminary work of training observers is progressing, and an outlying station about 15 miles distant southeast of the College has been selected and the distance measured by triangulation. Some good photographs have been obtained. Increased interest is manifested by voluntary observers at northern points. Theoretical investigations have been continued by Hulburt.

Atmospheric electricity--Much theoretical work, as well as practical measurements of various phases of atmospheric and terrestrial electricity, has been done by the Carnegie Institution and is reported separately. At Stanford University some problems having a meteorological bearing are under investigation. Professor J. G. Brown is continuing his work on the relation of space-charge to air-movements by means of a sensitive anemograph, and provision has been made for continuous records of both space-charge and potential gradient at two elevations--near the surface and about 50 feet above the surface. A graduate student at Stanford is at work on the causes of the variation of space-charge during fog and rain, and another student is working on a theory of thunder-storm electricity and the mechanism of lightning-discharge.

Professor Jensen at Nebraska Wesleyan is studying thunder-storms, having secured a large number of photographs of lightning-discharge and records of field-change, together with records of barometric variation from a group of microbarographs.

The Navy Department is at work on the problem of suitable static-direction finders for the purpose of tracking West Indian hurricanes and predicting thunder-storms in the vicinity of Naval air-stations.

Kennelly-Heaviside layer-height--Cooperation between various organizations represented in the Section has been in effect in work on this problem, and reports of those efforts are given separately. The Bureau of Standards, Tufts College, Harvard University, the Naval Research Laboratory, the Carnegie Institution of Washington, and Perkins Observatory are among those interested. Researches at the Bureau of Standards have established the existence of a layer of fairly constant height at about 110 kilometers and another layer at a great height which varies with conditions such as time of day or season of the year.

Magnetic and electrical methods in prospecting--At Massachusetts Institute of Technology, research work on an electrical method of geophysical prospecting is in progress but not ready for report. The Bureau of Mines has made a study of electromagnetic absorption of limestone and sandstone at Mammoth Cave and a comparison of the magnetic and electric methods of distinguishing dikes in the Sudbury district in Canada. The diabase dikes containing magnetite and the nickel-copper ore dikes cannot be differentiated by the magnetometer, but show distinct differences by the induction-method. By a combination of the two methods it is easily possible to distinguish these two types without following them to the outcrop. The Colorado School of Mines has been using a number of magnetometers in the field and has been developing fast and accurate methods of standardization. The results in some cases have been checked by the torsion-balance. A new electrical resistivity-instrument of the Gish-Rooney type has been built with some improvements and has been found very useful. They are also experimenting with the potential-drop method using the Racom compensator.

Ozone--The spectra of ozone brought back from Antarctica have been examined at the Naval Research Laboratory, where a thickness of 0.28 cm was indicated for both the polar day and the polar night. At the Smithsonian Institution a new method of determining atmospheric ozone from bolographs of visible spectra has been devised by Abbot and in cooperation with observers at Table Mountain has been improved and standardized by Wulf.

Solar radiation and solar activity--The Smithsonian Institution has continued the operation of three solar-radiation stations, Table Mountain (California), Montezuma (Chile), and Mount Brukkaros (Southwest Africa), and an expedition has been dispatched to investigate other sites in Southwest Africa and in the Cape Verde Islands. The Montezuma results are published daily and are being broadcast by Science Service. A satisfactory method has been devised for the reduction of the Table Mountain observations, which show good agreement with those of Montezuma, the difference in monthly means being about one-sixth per cent. At Mount Wilson solar character-figures which indicate solar activity estimated from calcium and hydrogen spectroheliograms show no marked connection with the magnetic character-figures. Investigations show that just previous to each magnetic storm localized disturbances are nearly always present in or near active sunspot-groups. Hale has found that several extraordinary outbursts of this nature were followed by expectional magnetic storms, the interval between the two being on the average a little more than a day. The effects of solar activity on telephone and radio transmission have been the subject of investigations at the Bureau of Standards and by the Bell System.

Earth-currents--Earth-currents are being studied in this country by a cooperation between the Carnegie Institution, the Coast Survey, and the American Telephone and Telegraph Company, also by the Bell System and Tufts College. A recorder is being put into operation by the Telephone Company which will measure the voltage induced in two insulated loops near New York, each inclosing an area of 20,000 kilometers or more. This work is to be extended if results warrant.

Cosmic influences--The correlation of radio reception with the moon's position has been the subject of an investigation by Stetson. The break-up of comets has been found by Maris to bear a time-relation to the occurrence of magnetic storms, indicating a common cause. The amount of the net electrical charge on the Sun or typical star has been theoretically determined by Gunn to be not more than one coulomb. Millikan and Cameron by observing at Pasadena and Churchill (750 miles from the north magnetic pole) find the intensity of cosmic radiation the same at both places and therefore not influenced by the Earth's magnetic field.

Broadcast service--Cooperating with the American Section of the International Scientific Radio Union, Science Service is collecting daily data on terrestrial magnetism, the solar constant, sunspots, and auroral displays for broadcast and distribution otherwise to those interested. The Signal Corps, through the War Department Message Center, has cooperated in this work. They report an average time of 15 to 20 minutes from Mount Wilson to destination, and 35 to 40 minutes from Tucson to destination. Science Service messages were given priority in the War Department radio net. A decoded summary of these messages is published quarterly in the Journal of Terrestrial Magnetism and Atmospheric Electricity.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

REPORTS SUBMITTED ON WORK IN TERRESTRIAL MAGNETISM AND ATMOSPHERIC ELECTRICITY

Auroral work at the Alaska Agricultural College and School of Mines

In regard to the auroral work which we are doing at the Alaska Agricultural College and School of Mines with the generous support of the Rockefeller Foundation, progress has been made in what seems a satisfactory manner. Starting about the middle of last August two transmitters and receivers were made here to be used on the 80-meter amateur band. This band was chosen because it was desired to use radio phone as well as code. One of these units was placed in a carrying-case to be used as a portable station; the other, a 7 1/2-watt transmitter with a receiver, was installed permanently in the writer s home here on the campus. Next an operator was trained and the licenses were obtained for the two stations.

The location of the outlying station having been selected, the work of getting its distance from the college-station was started. The method of triangulation was used, using as a base-line a system previously located and established by the Coast and Geodetic Survey and by the Land Office survey. The work proved to be difficult due to bad weather and poor visibility, and it was found necessary to turn all angles at night using gasoline-lanterns as targets. Professor R. W. Chase of the Civil Engineering Department supervised this work. The site chosen for the outlying station (station No. 2) lies about 15 miles almost due southeast from the College. It offers a clear view in all directions and is on the highway. There was an old cabin which with some repairs was made suitable for use this year but should be replaced this summer. Early in the fall a student was trained to act as observer for station No. 2. This necessitated the teaching of a sufficiently large number of stars so that he could recognize them without difficulty.

Enough "8-minute exposures" for this year's calculations have been made to construct "network" charts after the plan of Professor Horang. This work has not been finished and will be continued next fall.

The above represents the preliminary work which has been carried out. Some changes will have to be made in order to perfect the plan of observation for coming years. Some additional equipment will also be necessary.

As to the number of auroral photographs taken with the two cameras (designed and tested by Störmer in Norway) for purposes of measurement, the report is not what one could wish. We have so far succeeded in getting only about three dozen photographs which it is believed are capable of being measured in addition to many which have failed. The work of making sketches and calculating has not been begun since duties at the College have so far afforded no opportunity for doing so. This work will be started, however, as soon as the aurora season is over for the year.

The problem of accurate time is still unsolved and has given a good deal of anxiety. An attempt was made to get time-signals through the Signal Corps but this failed because of irregularity and inaccuracies in relaying which is done manually. So far no radio receiver has been found capable of even fair reliability to receive the signals direct from Arlington.

V. R. Fuller,
Professor, Department of Physics

College, Alaska, April 1, 1931

Work of the Bell System relating to terrestrial magnetism and electricity

Although the wire-line services of the Bell System are conducted in such a manner as not to be greatly affected by magnetic disturbances, the radio extensions to foreign countries and to ships at sea are frequently markedly influenced. The only radio-telephone channel now utilizing long waves is on the average improved on disturbed days. However, there are three short-wave telephone-channels operating over the North Atlantic that are so adversely affected as to be rendered useless for periods varying from a few hours to perhaps one or two days. It is this aspect of terrestrial magnetism with which the Bell System is at present most interested. Earth-potential

disturbances have been found to correlate rather closely with abnormal radio transmission. This fact, together with the facility with which such observations may be made, has led to considerable study of these phenomena.

The research-groups of the Bell System have been active for some time in studying the characteristics of radio transmission and their correlation with various solar and terrestrial phenomena. The following papers giving the results of such work have been published (others are in preparation):

Transatlantic radio-telephone transmission. Lloyd Espenschied, C. N. Anderson, and Austin Bailey. Proc. I.R.E., v. 14, 7-56 (January 1926).
Correlation of long-wave transatlantic radio transmission with other factors affected by solar activity. C. N. Anderson. Proc. I.R.E., v. 16, 297-347 (March 1928).
Notes on the effect of solar disturbances on transatlantic radio transmission. C. N. Anderson. Proc. I.R.E., v. 17, 1528-1536 (September 1929).
Transoceanic telephone service--short-wave transmission. Ralph Brown. Trans. A.I.E.E., v. 48, 624-628 (April 1930).
Overseas radio extensions to wire-telephone networks. Lloyd Espenschied and W. Wilson. Proc. I.R.E., v. 19, 282-303 (February 1931).
Some observations of the behavior of earth-currents and their correlation with magnetic disturbances and radio transmission (in preparation).

Outlined below is only that portion of the work relating to earth-potentials.

For a period of about three years there have been recorded more or less continuously the potentials prevailing on two grounded circuits extending to points roughly 150 kilometers to the north and to the west, respectively, from New York. The major earth-potential disturbances noted within this time have closely resembled the corresponding magnetic variations reported by the principal observatories of this continent. There have been many minor disturbances of which there were no reports by the magnetic observatories. Attempts have been made on tranquil days to obtain diurnal-variation characteristics, but thus far these have been masked by potentials of industrial origin even though considerable care has been exercised in the choice of grounds.

More recently a second recorder has been added which at present is being used on various short supplementary lines near New York to detect any natural potentials of a more local origin which might not be noted on long lines. This latter phase of the work will soon be completed, after which measurements will begin on the voltage induced in two insulated loops, each enclosing areas of 20,000 square kilometers or more. This work may be extended if the results warrant. In addition to this work, observations are being made on Bell System lines by the Department of Terrestrial Magnetism of the Carnegie Institution in cooperation with the United States Coast and Geodetic Survey and by the Department of Electrical Engineering of Tufts College at points near Tucson, Arizona, and Boston, Massachusetts, respectively.

A routine was established about 1913, whereby visual voltmeter-measurements would be made by operators at strategic points throughout the United States at times of disturbances. This scheme was not particularly successful largely because the observers had other responsibilities at times of disturbance which preclude continuous observation. It was, therefore, discontinued about three years ago. The most important results of this phase of the work have recently been described by O. H. Gish of the Department of Terrestrial Magnetism of the Carnegie Institution (Sci. Mon.,v. 32, 5, January 1931).

Otto B. Blackwell,
New York, New York, March 2, 1931 Transmission Development Engineer

Researches at Mount Wilson Observatory of the Carnegie Institution of Washington relating to terrestrial magnetism

Continuous records of horizontal intensity and declination have been continued at Mount Wilson during the past year. A preliminary comparison of solar character-figures, which indicate the solar activity as estimated from calcium and hydrogen spectroheliograms, with the magnetic character-figures shows no marked connection. A study being

made of the solar conditions just previous to each magnetic storm indicates that localized disturbances in or near active sunspot-groups are nearly always present. These disturbances are most readily detected by the presence of bright clouds of hydrogen which show rapid changes. The association of such phenomena with magnetic storms has long been recognized. The present investigation aims to collect observations of such phenomena relating to all the moderate or more intense magnetic storms covered by the Mount Wilson records in an effort to arrive at a statistical understanding of the facts involved. At present the results indicate that the importance of the active region being in a central position on the Sun's disc at the time of a magnetic storm has perhaps been overestimated.

Dr. Hale has collected accounts of several extraordinary outbursts of this nature which were followed by exceptional magnetic disturbances on the Earth, and these will be published soon in the Mount Wilson contributions. He concludes from this evidence that, on the average, a little over a day elapses after the beginning of such an outburst before its effect on the Earth's magnetic field is observed. A systematic program of observing with spectroheliroscopes, many of which are now installed at stations widely separated in longitude, is being developed for the purpose of obtaining a more continuous record of this type of solar activity which is often of comparatively short duration.

Seth B. Nicholson

Pasadena, California, April 15, 1931

Work in magnetic and electrical prospecting at Colorado School of Mines

During the past year, we have directed our attention to the perfection of accurate and fast methods for the determination of the temperature-coefficients and scale-values of field-magnetometers. We have found that the galvanometric method of scale-value determination is more accurate and just as rapid as the magnetic method despite the fact that it involves a little more cumbersome equipment.

We have acquired a recorder for the diurnal variations and if time permits expect to compare the magnetic variations in this area with those recorded in other magnetic observatories.

At present, we are also interested in, and have developed, a method to determine the magnetic effects of ore-bodies and structures by model-experiments. We use an earth-inductor arrangement for that purpose. The coil is driven by a synchronous motor and the variations in current induced by the ore-bodies are observed on a potentiometer. The arrangement is so made that the normal value of the intensity as well as the diurnal variations during the experiment cancel out.

As far as our magnetic field-work is concerned, we have continued our investigation of the eastern part of the State of Colorado with a number of magnetometers and have arrived at a number of very interesting results on the effects of possible oil-structures. Part of the results have been checked by means of a torsion-balance.

As far as our work on terrestrial electricity is concerned, we have recently built a small new equipment for the Gish-Rooney method which we have found extremely useful in our field-work. This equipment differs from our preceding Gish-Rooney apparatus in that the commutator does not have to be cranked by hand but is driven by motor. Furthermore, the arrangement of wires and electrodes is so made that the electrical measuring-apparatus is left stationary at one point while measuring the resistivity along one traverse.

We have also begun experiments with the new potential-drop ratio-method and are using the Racom compensator furnished by the courtesy of the Swedish American Prospecting Corporation.

A stimulus to our electrical work has been a cooperative program worked out by the Colorado School of Mines and the Agricultural College of Colorado the object of which is to locate the depth to ground-water throughout great portions of the eastern part of our State.

C. A. Heiland,
Professor, Department of Geophysics

Golden, Colorado, April 28, 1931

Magnetic work of the Dominion Observatory during 1930-1931

The work of the year 1930 marked the inception of a program that has for its objective the reoccupation of repeat-stations for secular change. These stations number about 200 and are distributed from, and including, the coast of Labrador to the islands along the coast of British Columbia, and from the Canada-United States boundary to as far north as the Yukon-Alaska boundary on Yukon River, to the mouth of the Mackenzie, to the northern boundary of Manitoba, to north of Churchill on Hudson Bay, to Port Albany on James Bay, and to Hudson Strait. The area mentioned represents that part of Canada thus far covered by the general magnetic survey.

During the year 1930, forty-seven repeat-stations were occupied. With the exception of three northerly stations, namely, The Pas, Mile 200, H. B. Ry., and Churchill, the season's operations were confined to that area lying between longitudes 75° west and 116° west, and the Canada-United States boundary and latitude 53° north.

In addition, the magnetic instruments were compared with the standard instruments of the Meteorological Service at Agincourt in January 1930 and recently a thorough comparison has been completed with those of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington.

R. Meldrum Stewart,
Ottawa, Canada, April 20, 1931 Director

Investigations of thunder-storms at Nebraska Wesleyan University during 1930

The thunder-storm season of 1930 was not a very satisfactory one in Nebraska. However, we did have a few very violent storms, and records were obtained from five or six of these which are fairly complete. On one storm along about 50 photographs of lightning-discharges were obtained together with field-change data for each of the flashes photographed. Considerable data have also been accumulated regarding barometric variations as the storm passes over, using for the purpose a battery of four microbarographs. The microbarographs are working out very satisfactorily in helping determine positively whether a storm has gone overhead and the approximate time which elapsed while the storm was passing from one instrument to the next in line. A hundred or more photographs were obtained of lightning-flashes for which we have complete data of field-changes and distance to the discherge, as suggested by Simpson. The writer's working hypothesis is that the Simpson theory is correct, rather than that of Wilson, positive charges being in the majority during the first part of the storm and negative charges succeeding thereafter. If the storm does not go directly overhead, only the negative portion of a storm would affect the observer's instruments. Since, according to Simpson's picture, the negative part of the cloud is much larger than the positive, this would help to account for the excess of negative charges recorded by Wilson, Schonland, and others. The observations thus far obtained support this hypothesis in a general way.

J. C. Jensen,
Lincoln, Nebraska, April 20, 1931 Professor, Department of Physics

Recent solar-constant work by the Smithsonian Institution

Three stations, Table Mountain (California), Montezuma (Chile), and Mount Brukkaros (Southwest Africa), have been in active operation. Each observes the solar-constant, usually five times per day, on about 80 per cent of all days in the year. But a considerable proportion of the days observed are found unsatisfactory, so that only about 60 per cent of those in the year are really useful. Unfortunately all stations show many lapses from January to March.

Montezuma results are definitive and have been published daily on United States Weather Bureau maps for several years. They have also been broadcasted daily since July 1930 by Science Service. Table Mountain results have been reduced several times without satisfaction by the process used successfully at Montezuma. Last autumn a new process was invented by Abbot, which has now been applied with satisfactory results for all Table Mountain observations. The monthly mean values since December

1925 differ on the average about one-sixth per cent from those of Montezuma, and thus show almost identically the same general results on solar variation. In many instances the short-interval solar variations are also closely duplicated in the results at both stations.

The new process of reduction is being applied to Mount Brukkaros results, but as yet we cannot predict with what success.

With a grant from John A. Roebling, A. F. Moore has gone for a year's absence to investigate the advantages for solar-constant stations of the peak of Fogo, in the Cape Verde Islands, and of certain peaks in Southwest Africa as compared to Mount Brukkaros. He has simple apparatus for measuring sky-brightness, pyrheliometry, and precipitable water at the stations examined.

Abbot has published a paper entitled "Weather dominated by solar changes." It consists of three parts. Part I shows that the temperature and barometric pressure in the United States both exhibit opposite and large deviations when associated, respectively, with rising and with falling solar-constant sequences, as observed in Chile. Part II shows that the variation of the monthly mean solar-constant values since 1918 can be very closely expressed as the sum of five and only five regular periodicities. These periods are, respectively, 68, 45, 25, 11, and 8 months. Part III shows that the monthly mean variations from the normal of Washington temperatures can be fairly closely represented as the sum of six periodicities, respectively, of 68, 45, 25, 18, 11, and 8 months.

A new method of determining atmospheric ozone from bolographs of the visible spectrum has been devised by Abbot. It is satisfactory for correcting solar-constant results for ozone absorption. Under a grant from John A. Roebling, Wulf has worked at Table Mountain in cooperation with our observers there, and has made accurate standardizations and improvements of this new ozone method. Wulf's results will be published soon.

Volume V of the Annals of the Astrophysical Observatory, containing results of 1920-1930, is nearly ready to go to press. It will be published this autumn.

C. G. Abbot,
Secretary

Washington, D. C., March 16, 1931

Research in atmospheric electricity at Stanford University

Three problems in atmospheric electricity are being investigated at Stanford University, all relating to meteorological influences.

In the Physics Department, J. G. Brown is continuing his work on the relation of space-charge and potential gradient to the movements of the air. A sensitive anemograph has been developed and an observation-hut is being built with equipment for obtaining continuous records of both space-charge and potential gradient at two elevations, one near the surface and the other 50 feet above the surface. It is believed that with these data progressive changes due to air-movements can be studied in greater detail. The records of the past year have been more reliable than before because of improvements, and they further support the theory that the diurnal variation of the potential gradient is at least partly a result of a diurnal system of air-movements which change the distribution of the space-charge.

P. D. Williams, a graduate student in the Physics Department, has started an investigation to determine if possible any selective effects upon ions by nuclei and water-vapor in the air. This is a laboratory-problem with controlled conditions, and is preliminary to the explanation of the variations of space-charge and potential gradient which occur during fog and rain.

E. A. Evans, a graduate student in the Electrical Engineering Department, is working upon a theory of thunder-storm electricity, the particular factors considered being (1) the ionization of clouds, (2)the electro-physical phenomena accompanying cloud-volume discharges, and (3) the mechanism of the lightning-stroke. The observa-

tional data upon which the problem rests were obtained during two years of field-investigation of lightning with the General Electric Company in Pennsylvania and observations of thunder-storm phenomena during one summer in Colorado. Further field-work is planned for next summer.

Joseph G. Brown,
Professor, Department of Physics
Stanford University, California, March 21, 1931

The precise declination-survey of the Topographical Survey, Department of the Interior, Canada

The needle of the magnetic compass does not point true north but more or less to the east or west at different places. Thus at Halifax, Nova Scotia, it points 23° west of true north; at Ottawa, Ontario, 15°6 west of true north; and at Victoria, British Columbia, 25° east of true north; while at some places in northern Canada it actually points dead south. That the compass may be used with reliance, therefore, the various countries measure the true direction, the "declination" or "variation" as it is called, of the needle at many places and show it on declination-charts. With the aid of such a declination-chart, the magnetic compass becomes the universal pathfinder on the seas, on the Earth, above the Earth, and underground. All vessels and aeroplanes carry a compass, and water- and air-navigation would be nearly impossible without it. It is used on some land-surveys; and in surveying timber-berths, mineral claims, railroad-locations, etc. It is used for locating underground minerals, surveying mines, and running mine-tunnels. It is the guide of pioneers and settlers, prospectors and miners, timber-cruisers and foresters, hunters and trappers, etc. Only by its aid can the prospector penetrate the forest in safety.

At an early date it was seen by the Topographical Survey that its parties were uniquely qualified to measure the true direction of the compass-needle at many places and at minimum cost because the parties were covering so many parts of the Dominion and because such measurements take but a few minutes when combined with the other work. Since 1880, therefore, such practical measurements of the true direction of the compass-needle have been made by the Topographical Survey until they now total 28,000, constituting one of the largest and most economical precise declination-surveys in the world.

Many Dominion and Provincial Government offices and individuals are aiding in this practical work under cooperative arrangements whereby the Topographical Survey supplies instructions, looks after the instruments, and computes the results. To mention but one case of many: The Surveyor General of Ontario has the Ontario Government surveyors measure the true direction of the compass-needle at many places on their work, while the Topographical Survey looks after their instruments and computes their results.

All precise declination-information for Canada from all other sources is filed by the Topographical Survey. To make all this information readily available to the public in the cheapest and handiest form, the practice of other countries of publishing declination-charts at five-year intervals is followed. The Topographical Survey also publishes up-to-date compass-information on its National topographic map-sheets, air-navigation maps, etc., for the areas such maps cover, and supplies similar information to other offices.

The compass-needle not only has a different direction at each place, but, in addition to its diurnal variation, changes its direction from year to year in a very confusing manner. Thus at Toronto, Ontario, it pointed north 3° 21' west in 1750, north 0° 28' west in 1800, north 1° 39' west in 1850, north 4° 59' west in 1900, and north 6° 53' west in 1930. As all old land-boundaries in Canada were laid down by compass, when it is now desired to retrace an old lost land-boundary it is necessary to know how much the compass-needle has changed direction at that point in the meantime. Such information is also necessary for keeping up-to-date all past measurements of compass-needle direction.

The Topographical Survey, therefore, in conjunction with its other work and in cooperation with the Provinces, marks certain places, called repeat-stations, with

bronze tablets where it measures the change in compass-needle direction from time to time. The Survey collects all information in regard to the yearly change in direction of the compass-needle, adds it to its own, combines the total into tables for many places in Canada, and publishes the results. The accuracy of the precise declination-work is guaranteed by having the instruments standardized at the beginning and end of each season at the Magnetic Observatory, Agincourt, Ontario, by the cooperation of the Meteorological Service of Canada.

The object of the Topographical Survey has always been to acquire the maximum compass-information at minimum cost, either directly or by cooperation, and to supply it to the public without delay.

F. H. Peters,
Ottawa, Canada, April 28, 1931 Director

Geophysical work of the Bureau of Mines

In the summer of 1930 a careful study was made regarding the amount of absorption which takes place when electromagnetic energy passes through a conducting medium consisting of limestone and sandstone, at the Mammoth Cave of Kentucky. It was found that this absorption, which had a frequency of 500 cycles per second, was of the order of five to ten per cent after passing through about 100 feet of earth. This amount of absorption is not excessive and will not restrict prospecting-methods using this frequency.

A careful study was made concerning the ability to distinguish dikes in the Sudbury district of Canada by geophysical methods. It is well known that in this district there exist two kinds of dikes, one referred to as the diabase dike, made magnetic by the disseminated magnetite contained in the formation, the other consisting primarily of the well-known nickel deposits of the district which are also magnetic. The reaction upon the magnetometer is essentially the same for either of these formations and no discrimination is possible by magnetic observations. On the other hand, the electrical conductivities of the two systems are entirely different. Induction-methods when applied to the diabase dike offer no detectable reaction, while the ore-veins of the nickel-copper ores show a distinct difference in electrical conductivity and offer a very distinct reaction to induction-methods. It was found by combining these two geophysical methods that it was easily possible to distinguish these two types of subterranean formations without following them until they outcrop.

Further tests were made concerning the degree of differentiation which could be established by the variations of electrical conductivity measured at the surface of the ground, especially in determining regions of high resistivity such as would be caused by the segregation of oil. It was found that these resistivity-measurements have very distinct advantages in geological differentiation in districts where it is difficult to interpret geology from the surface indications.

We are greatly indebted in this connection to the Carnegie Institution of Washington for helping us to secure proper instruments for making resistivity-measurements.

Scott Turner,
Washington, D. C., March 17, 1931 Director

Work on terrestrial magnetism or electricity by Bureau of Standards

The Bureau of Standards has conducted no research in terrestrial magnetism or atmospheric electricity. It does carry on an extensive research program on radio-wave transmission. During the past year the work has included (a) the recording of received field-intensities of transmissions from broadcasting stations, (b) measurements of intensity of received waves and atmospheric disturbances at low radio-frequencies, (c) height of the Kennelly-Heaviside layer, and (d) observations on radio-transmission conditions in Antarctic regions.

The work on the recording of broadcast-station reception is done by automatic and semi-automatic recorders. Information on fading, polarization, and other properties of

the waves is accumulated. The measurements have indicated that magnetic storms do not affect the received wave-intensities, but increase atmospheric disturbances. The eclipse of April 28, 1930, did not affect the records.

The observations on low frequencies have indicated correlations with solar and magnetic activity. Some connection has been shown between the annual averages of sunspot-numbers and daylight radio field-intensities from some transatlantic stations. A definite correlation has appeared between monthly averages of transatlantic field-intensities and terrestrial magnetic activity. This work is described in a publication "Solar and magnetic activity and radio transmission" by L. W. Austin, E. B. Judson, and I. J. Wymore-Shiel (Proc. Inst. Radio Engin., v. 18, 1997-2002, December 1930).

The height of the Kennelly-Heaviside layer is measured by means of pulse-signals transmitted from a special transmitter and received a few miles away. The difference in time of arrival between the waves traveling along the ground and those reflected from the Kennelly-Heaviside layer is measured on an oscillograph. The observations, which continue in progress, have been made over a wide range of frequencies, especially at very high frequencies. They show variations in the height of the layer with time of day and time of year. The effects are brought out with particular clarity by their study at various radio-frequencies. The research has established the existence of a layer of fairly constant height at about 110 km and another layer at a greater height which varies with the conditions just mentioned. Some of the results obtained are described in the papers "Kennelly-Heaviside layer-height observations for 4,045 and 8,650 kilocycles" by T. R. Gilliland and "Kennelly-Heaviside layer studies" by P. A. DeMars, T. R. Gilliland, G. W. Kenrick (Proc. Inst. Radio Engin., v. 19, 114-119 and 106-113, January 1931).

A member of the Bureau accompanied the Byrd Antarctic Expedition and made studies of radio transmission in Antarctica and also in New Zealand. Studies of radio transmission from Europe and America to Antarctica were made, as well as special observations of shorter-distance transmission in Antarctic regions. Some of the observations indicated an effect of the south magnetic pole. The long-distance observations resulted in comprehensive information on the variation of transmission-distances with frequency, time of day, and time of year. An excellent correlation between received wave-intensities in the darkened area included in the transmission-path was one of the results of this research.

George K. Burgess,
Director

Washington, D. C., March 26, 1931

Work of the Hydrographic Office of United States Navy Department

The work of the Hydrographic Office of special interest to the Section of Terrestrial Magnetism and Electricity was fully reported last year following the completion of the world-charts for 1930 of the variation of the compass, the inclination, and the horizontal intensity of the Earth's magnetic field.

The U.S.S. Fulton, one of the survey-ships of the Navy now engaged in surveying the Gulf of Panama, will investigate shortly reported magnetic disturbances off Cape Mala and the Island of Coiba, R.P.

The Navy Department is investigating the relation of static to storms. Static recorders operating on the principle of a revolving-loop radio-compass have not given the desired results. Steps are being taken to construct visual static direction-finders, which will be located at key-stations covering the Atlantic coast, Gulf of Mexico, and Caribbean Sea area. Use of them will be made in tracking West Indian hurricanes, and in forecasting local thunder-storms near Naval air-stations. The National Research Council will be informed when satisfactory results are obtained.

W. R. Gherardi, Rear Admiral, U.S.Navy,
Hydrographer

Washington, D. C., March 23, 1931

Progress-report of Naval Research Laboratory

The following is a brief statement of the work related to terrestrial magnetism and electricity of the Naval Research Laboratory during the past year.

A. H. Taylor measured the skip-distances of short radio-waves seven to fifteen meters. Taylor, Young, and Kenrick continued the observations on the short-time echoes of short radio-waves received occasionally inside of the normal skip-zones.

R. Gunn continued his theoretical development of the electromagnetism of the Sun and its atmosphere and the bearing on the observed solar rotation. Gunn showed that the solar diurnal quiet-day variation in the Earth's magnetism could not be used, as Chapman used it, to calculate the electrical conductivity of the Earth's core; he concluded that Chapman's value was probably too low by several orders of magnitude.

H. B. Maris completed a careful list of terrestrial magnetic disturbances observed from 1839 to 1930. From this he drew the average curve of the seasonal variation of magnetic disturbance and showed that this was well accounted for by the ultraviolet-light theory of magnetic storms. Maris further found that three very famous cases of the break-up of large comets occurred at epochs of strong terrestrial magnetic disturbance and showed that Jean's suggestion of solar gravitation as the cause of the break-up seems difficult to believe.

E. O. Hulburt continued the development of the ultraviolet-light theory of aurorae and magnetic storms, bringing out further details in agreement with observation. He calculated the atmospheric ionization by cosmic rays, and concluded that C. T. R. Wilson's hypothesis of "run-away" electrons from thunder-clouds as the cause of the penetrating-radiation did not account for the facts as observed by Millikan. Hulburt developed an atmospheric ion-theory of the zodiacal light and the gegenschein.

M. P. Hanson of this Laboratory, in charge of radio of the Byrd Antarctic Expedition, brought back solar and lunar spectra taken at Little America, Antarctica. From these spectra the ozone in the upper atmosphere above Little America came out to be about 0.28 cm in thickness during the Antarctic day, and roughly the same value during the Antarctic night.

E. O. Hulburt,
Superintendent, Heat and Light Division.

Bellevue, Anacostia, D. C., April 14, 1931

Work of the Signal Corps of the United States Army

The War Department Message Center has handled Science Service messages from Mount Wilson, California, and Tucson, Arizona, since August 1930. Up to and including February 28, 1931, the Signal Corps has handled 302 messages having a word count of 2,434 words and a value, if sent by commercial wire, of $348.42.

The average message-time on Science Service messages from Mount Wilson over the entire period ran from 15 to 20 minutes from point of origin to destination. The average time from Tucson ran from 35 to 40 minutes. Science Service messages were given priority service by the War Department Radio Net.

G. E. Kumpe, Colonel, Signal Corps,
Acting Chief Signal Officer of the Army

Washington, D. C., March 17, 1931

THE STOCKHOLM ASSEMBLY OF THE INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS--PROCEEDINGS OF THE SECTION OF TERRESTRIAL MAGNETISM AND ELECTRICITY

H. D. Harradon

The Fourth General Assembly of the International Union of Geodesy and Geophysics was held in Stockholm, Sweden, during August 15-23, 1930. The attendance was larger than at any previous meeting of the Union, there being present about 300 official delegates and guests representing 36 countries. The delegation from the United States, 14 delegates and three official guests, was also larger than at any previous assembly; with the accompanying members of families the total number from the United States was 27.

The Swedish National Committee left nothing to be desired in the matter of arrangements for the accommodation and entertainment of the visitors. It had secured for the use of the Union the Swedish Parliament House, the large auditorium of which was admirably suitable for holding the general meetings as were also the smaller chambers for the meetings of the sections. For the convenience of the delegates, there were also installed in the building a temporary bank, post-office, and bureau of information.

The meetings of the Section of Terrestrial Magnetism and Electricity began on the morning of August 16. The general regret of all that L. A. Bauer, President of the Section, owing to his prolonged illness, was unable to be present was formally expressed in a telegram of sympathy sent him by the Section. In his place, Vice-President Carlheim-Gyllenskold presided at all the meetings of the Section. The crowded agenda, which called for the consideration of a large number of the outstanding problems in terrestrial magnetism and electricity, were treated as fully as the limited time permitted.

After the opening address of the Vice-President and the Secretary s report on the activities of the Section since the last meeting in 1927 had been read and business of administrative and financial nature had been disposed of, the reports of the national committees were presented. These reports, to be printed in full in the Transactions of the Section, indicated sustained interest in the countries concerned and good progress in magnetic-survey and observatory-work despite unfavorable economic conditions which prevailed during the period covered by the reports. At this meeting Germany was for the first time represented, and A. Nippoldt of the German Meteorological Institute at Potsdam, also presented a report on the magnetic work in Germany which, on the motion of Secretary Maurain, it was voted to print in the Transactions in the German language.

Among the reports of various committees and discussions of special subjects following resolutions adopted at the Prague Assembly, brief mention may be made of the following: Chairman A. Crichton Mitchell of the committee on criteria of measures of magnetic activity presented a detailed report recommending certain formulas for characterization of days. The report was adopted and arrangements were proposed whereby data depending on the use of one of these formulas should be included in the quarterly publication "Caractere magnétique de chaque jour" issued at De Bilt under the auspices of the International Commission of Terrestrial Magnetism and Atmospheric Electricity. There was also presented the report of a special committee (S. Chapman and D. la Cour) on a scheme of international collaboration to advance the study of lunar effects on geophysical phenomena.

Chairman Carl Störmer of a committee appointed at the Prague meeting for the preparation of an auroral atlas, presented the report of his committee and laid before the Section at atlas of auroral forms with 48 photographic reproductions representing the different types and a scheme for visual observations of the aurorae. It was decided that this atlas, which was published at the expense of the Section, should be distributed free of charge to all observers and organizations engaged in serious investigational work on the aurora. It was also considered advisable that additional information regarding the use of apparatus, which Störmer agreed to prepare in collaboration with the other members of the committee, should be published at the expense of the Section and distributed with the atlas. D. la Cour then exhibited a collection of twelve colored auroral reproductions published by the Danish Meteorological Insti-

tute, designed to supplement the auroral atlas, and which he proposed to distribute under the same conditions as the atlas.

Reports on investigations of disturbances caused by electric car-lines and on sudden commencements of magnetic storms were presented by A. Tanakadate. The desirability of developing a portable apparatus for recording at field-stations the variations of the magnetic elements for short periods was recognized but no communication was presented on that topic. A paper on earth-currents was presented by Ch. Maurain and E. Mathias gave an abstract of his latest investigations of lightning. The great importance of continuing intercomparisons of standard electromagnetic instruments, a matter which had received attention at previous meetings, was again emphasized. The question as to whether Greenwich or zonal time should be used in magnetic-observatory publications was reconsidered in accordance with the proposal of the American Geophysical Union and referred to a special committee for further study. A report on ion-counters was presented by J. A. Fleming stressing the importance of their standardization; as a result of a discussion of this matter a resolution was passed by the Section whereby the Department of Terrestrial Magnetism of the Carnegie Institution of Washington was designated as a central office to which data pertaining to ion-counters could be referred for compilation, discussion, and determination of standards. On the proposal of Ch. Maurain, it was decided that the various suggestions made on the subject of terminology and symbols should be published and recommended. A communication by S. Chapman on the theory of solar and lunar diurnal variations of terrestrial magnetism was discussed by Whipple, Vegard, and Dobson. Ch. Maurain read a paper dealing with the electric field of the atmosphere and the selection of observations to be utilized. His conclusion was that for the study of general characteristics, one may confine oneself to electrically quiet days. Memoirs were presented on the new magnetic survey of France.

The question of the relations of the Section with the Commission of Terrestrial Magnetism and Atmospheric Electricity of the International Meteorological Committee was set forth in considerable detail by E. van Everdingen and led to a general exchange of opinions on the subject. However, in view of the fact that no real difficulty or duplication of work had thus far been encountered, it was thought best, for the present, to rely upon the respective officers to assure the harmonious functioning of the two bodies and to refer the matter for further examination to the committee appointed at Prague for this purpose.

The various items proposed by the American Geophysical Union were all placed on the agenda and given serious consideration by the International Section. Three of these had to do with (1) the selection of the most desirable distribution of additional observatories for magnetic and electric observations in order to cover the entire globe as completely as possible, (2) provision for insuring the reoccupation at regular intervals of a sufficient number of stations all over the globe to supply necessary data regarding secular changes of the Earth's magnetism, and (3) consideration of the division of observatory-work in Europe with a view to securing more valuable contributions without additional expense. The importance of these proposals was fully recognized at Stockholm and a committee consisting of J. A. Fleming, chairman, D. la Cour, S. Chapman, Ch. Maurain, and L. Rodes was appointed to plan for a better world-wide distribution of magnetic observatories particularly in the Southern Hemisphere where the need is most keenly felt and to bring about better coordination of work and publications of existing observatories.

Through the magnetic-survey work executed by various governments in their own territories, the scientific labors of numerous exploratory expeditions both public and private sent into the less accessible regions of the Earth, and especially the vast project of a magnetic survey of the globe conducted by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington during the last quarter-century, an enormous mass of observational material has been collected covering the greater part of the Earth's surface. These data will not be available for future use unless they be supplemented by observations for determining the secular change. It is evident from the recent studies of H. W. Fisk, results of which were presented before this Section a year ago, that the comparatively few foci of rapid change should be taken into account in the locating of new observatories and the planning of permanent repeat-stations. This important matter of truly international scope was fully discussed at the Stockholm meeting and, that it may be carried out as economically as

possible and the assistance of interested governments and private organizations elicited and utilized most effectively, a special committee consisting of Messrs. Carlheim-Gyllenskold, Chapman, Fleming, Heck, Kalinowski, Jolly, and Mathias was appointed to study the question and to assure the obtaining of well-distributed secular-variation data.

One of the resolutions passed by this Section last year favored the project of an International Polar Year for 1932-1933 which originated at the meeting of the International Meteorological Committee at Copenhagen in 1929. The urgent need of accurate observations in polar regions combined with the fact that increased facilities of communication, improved instrumental equipment, and new methods of discussion would yield results of inestimable assistance in the attack on outstanding geophysical problems the solution of which depends on data from the polar regions, led the Union to approve and support the following resolution which was favorably recommended by the sections of Terrestrial Magnetism and Electricity and of Meteorology:

"The Union accepts the invitation of the International Meteorological Committee to cooperate with them in organizing and carrying out a second Polar Year with a similar object to that of the first Polar Year 1882-1883, and appoints the following Commission for this purpose: Störmer (Chairman), Chapman, la Cour, Maurain, Wehrlé."

At a joint meeting of the sections of Terrestrial Magnetism and Electricity and of Meteorology, a subcommittee was appointed to report on the project of a second Polar Year. The resolutions proposed by this subcommittee and approved by the Section in its meeting on August 22, 1930, were as follows:

(1) The Subcommission appointed to report on the subject of a second Polar Year planned by the International Meteorological Organization considers that the project is of very great importance for the advancement of geophysical science. It also approves the suggestion that the observations should not be confined only to the polar regions.

(2) The Subcommission recommends that the Union should support the steps already taken by the International Meteorological Organization to effect international cooperation and in particular all members of the Union are requested to use their influence to obtain the active cooperation of their government and scientific institutions.

(3) The Subcommission is impressed with the desirability that all cameras and spectroscopes used in the observations of the aurora should be of equal sensitivity. It therefore recommends that the Magnetic Section should vote a sum of 15,000 gold francs for the provision of instruments of the standard type.

(4) The Subcommission recommends that all observations should be reduced according to an agreed plan, and that the Commission for the Polar Year should consider the best method for making the detailed observations available for study by all those interested. It also suggests that all published volumes should be put on sale and that the various sections of the Union should subscribe for a number of copies.

(5) The Subcommission recommends that the Section of Meteorology and the Section of Terrestrial Magnetism and Electricity should jointly submit the following resolution to the General Assembly of the Union: "The Union accepts the invitation of the International Meteorological Organization to cooperate with them in organizing and carrying out a second Polar Year with a similar object to that of the first Polar Year 1882-1883, and appoints the following Commission for this purpose: Störmer (Chairman), Chapman, la Cour, Maurain, Wehrlé.

At the final session on August 22, 1930, the election of officers of the Section and of its executive committee was held. The following were elected: J. A. Fleming, president; V. Carlheim-Gyllenskold, vice-president; Ch. Maurain, secretary; Crichton Mitchell, la Cour, Jaumotte, Palazzo, and Tanakadate, members of the executive committee.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

INVESTIGATIONS AT THE PERKINS OBSERVATORY OF CHANGES IN THE KENNELLY-HEAVISIDE LAYER AS A FUNCTION OF LUNAR ALTITUDES

H. T. Stetson

Observations of radio intensities by the writer and by G. W. Pickard have provided material for showing a close correlation between solar activity and the apparent level of the Kennelly-Heaviside layer as interpreted in measured signal-strengths. Recent investigations of accumulated radio data exhibit an apparent dependence of signal-strengths upon the position of the moon in the sky in respect to the path of transmission.

Preliminary deductions indicate that radio reception at 770 kilocycles over a stretch of 1,500 kilometers in an east and west direction is approximately 100 per cent poorer when the moon os overhead than when the moon is beneath the observer. Correlation-curves are exhibited both between radio intensities and lunar hour-angle, and radio intensities and lunar altitudes. Interpreting these results similarly as we interpret the correlation of radio intensities with solar activity, we are led to suppose that there is an alternate rise and fall in the Kennelly-Heaviside layer as a function of the lunar day.

It is suggested that this hypothetical electronic tide can be accounted for by supposing an electrostatic charge on the moon, placing it at a different potential from that of the Earth. The assumption of a negative charge on the Earth's satellite seems consistent with the observed results. The extraordinary change in the intensity of the signals when the moon is above the observer as compared to when the moon is below the observer does not seem to necessarily imply that there is a correspondingly radical change in the height of the ionized atmospheric layer. It is suggested that a plausible value of a negative charge on the moon may so change the interference of propagated waves as to produce radical changes in field-strengths at the Earth's surface, although a relatively small change in the height of the Kennelly-Heaviside layer is affected.

It should be stated that individual graphs for separate years show markedly the same effect so far as the relation between radio intensities and the position of the moon in the sky at the time of observation is concerned. The individual curve for the year 1928 does not show so markedly the general trend of the curves, but this may be accounted for on the basis of the fact that a secondary peak of sunspot-maximum occurred in 1928 which may have disturbed the lunar correlation. As upwards of a thousand observations are concerned, well distributed over the sunspot-curve of the years in question, it is believed that any effect of solar rotation is fairly well eliminated, especially since the sunspots occur at various degrees of latitude and no absolute value for the rotational period for solar disturbances can be assigned.

More extended observations are now in progress at the Perkins Observatory which will make possible a comparison of the radio intensities at different altitudes and hour-angles of the moon with even less danger of confusion with any possible solar cycle.

Attention is called to a paper in the Journal of Terrestrial Magnetism and Atmospheric Electricity for March 1931 (pp. 1-5) bearing upon the subject of this paper.

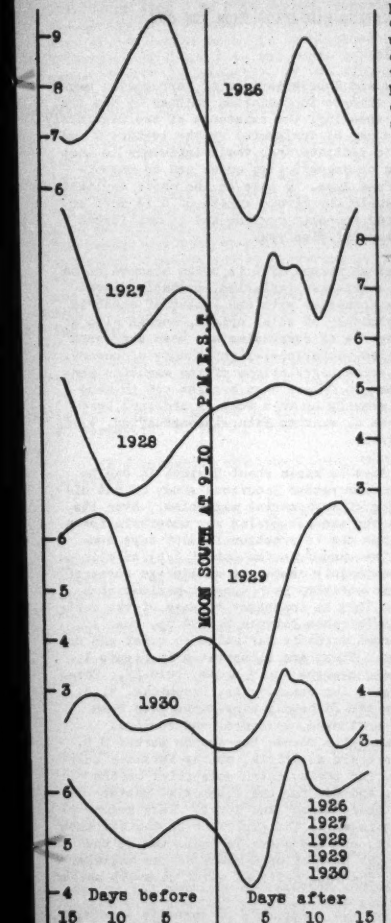
Note--Since presenting the above paper, my attention has been called to a paper by J. Egedal of the Meteorological Institute at Copenhagen (Nature, v. 123, 642, 1929) bearing upon the general problem of this investigation. It is significant that Egedal's recent studies in conductivity of the upper atmosphere show that observations of aurorae indicate a variation of some 25 per cent in the conductivity of the atmosphere at latitude 40° in the 100-kilometer region directly traceable to an atmospheric tide. Egedal concludes, "The existence of a resulting enormous variation of the height of the conducting-layer may be tested by means of radio waves."

Perkins Observatory,
Ohio Wesleyan University,
Delaware, Ohio

NOTES ON CORRELATION-INVESTIGATIONS BETWEEN KENNELLY-HEAVISIDE LAYER AND LUNAR ALTITUDES

Greenleaf W. Pickard

The preceding contribution by Stetson is an outstanding one to our knowledge of extra-terrestrial influences upon radio transmission. The writer is perhaps in a unique position to appreciate this work, for several years ago he searched for a lunar period in radio reception, obtained inconclusive results, and announced that there was little or no relation (The correlation of radio reception with solar activity and terrestrial magnetism, Proc. Inst. Radio Engin., v. 15, 92-93, February 1927); this discussion may be regarded as a recantation and abjuration of his former belief.



When, several months ago, Dr. Stetson told me of his results, I did not accept them until after checking them personally by a method slightly different from, and perhaps somewhat simpler than, the one he used. Taking text from the Old Farmers Almanac, which happened to be the only form of lunar tables then at hand, the dates were found when the moon was south between 9 and 10 p.m., Eastern Standard Time--the hour when WBBM was measured each evening. The figure first gives the relation between radio reception and moon south by years, and then, at the bottom of the figure, for the five-year period. With the exception of 1928--a highly disturbed year by reason of high solar activity--a reception-minimum is shown shortly after the moon is south, that is, shortly after the moon's maximum altitude above the horizon. The mean for five years indicates that in general the minimum is reached about four days after the moon is south--a substantial agreement with Stetson s results.

It would appear highly probable that there is a true lunar period of approximately 29.5 days in night radio reception, which on particularly sensitive transmission-paths and frequencies may show large amplitudes. Traces of this lunar effect are found in Brown s San Francisco-Pasadena measurements, but the writer has so far failed to find it in Austin s long series of Washington day fields from Mauen.

It is interesting, although probably inconclusive, to speculate on the mechanism of this lunar action on the Kennelly-Heaviside layer. As the moon is a cold body, it can hardly be a radiation-effect. Nor can the reflected sunlight have much effect, as its intensity is so low. Gravitational forces might produce a true tide in the layer just as they do in the atmosphere, but the amplitude should be vanishingly small. Magnetic effects are possible, and there is, I

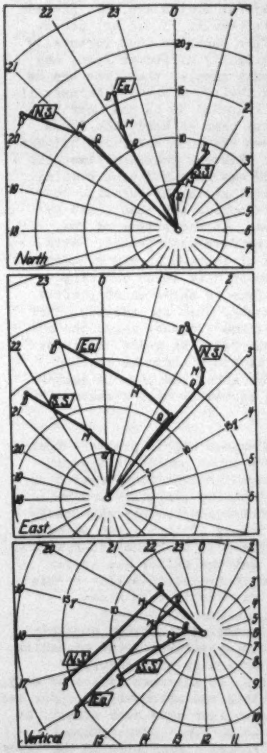
believe, a small amplitude lunar period in terrestrial magnetism. But Stetson's hypothesis of electrostatic action is certainly plausible. But even this is open to criticism, for Gunn has rather convincingly shown that it is unlikely that any body in our galaxy has any considerable electrical charge (Electrical state of the Sun, Phys. Rev., v. 37, 983-989, April 15, 1931).

Newton Centre, Massachusetts

USE OF MAGNETIC DATA FOR INVESTIGATING RADIATION FROM THE SUN

J. Bartels

1--The relations between solar phenomena and the variations of terrestrial magnetism have been interpreted as being due to changes in radiation emitted by the Sun. The observational evidence suggests, roughly speaking, the existence of two distinctly different kinds of such solar radiation; they may be designated by the letters Q and D, in order to indicate that their influence is most clearly shown on magnetically quiet and on magnetically disturbed days. Q acts on the whole daylight hemisphere, while the direct effect of D is more or less restricted to polar regions and is manifested at night in auroral displays.



The physical nature of Q is often assumed to be that of some short-wave radiation, probably ultraviolet. D is connected with the impact of electric corpuscles, probably of solar origin, though also a terrestrial source of corpuscles has been suggested in the so-called ultraviolet-light theory of aurora. Fairly close solar correlations of the magnetic phenomena ascribed to D have been brought out in many ways, and no summary of this work is proposed here (see Ergebnisse d. exakten Naturwissenschaften, v. 9, 38, Berlin, 1930).

2--Much less is known about Q since it can be inferred only from rather laborious study of the diurnal variation of terrestrial magnetism. Even its dependence on the sunspot-period was uncertain for a long time, since the international quiet days comprise always the same fraction (about 1/6) of all days, and so certainly represent an average state of higher magnetic activity near sunspot-maximum than near minimum. This is important because of the well-known great differences between S_q and S_d, that is, the solar diurnal magnetic variation on quiet and on disturbed days. These are illustrated in Figure 1, which gives mean results for Potsdam, 1916-27. Harmonic dials (see, for example, Zs. Geophysik, v. 3, 389, 1927) for the 24-hourly sine-waves have been drawn for the northward, eastward, and vertical component of magnetic force; the graphs marked N.S. are for the northern solstitial months November to February, S.S. for the southern solstitial months May to August, and Eq. for the equinoxial months September, October, March, and April. Each point represents a sine-wave; the amplitude is the distance from the origin, and the phase is indicated on the dial by the local time of occurrence of the maximum. The points for the international quiet days are marked

Fig. 1--Harmonic dials for east, north, and vertical components of magnetic intensity, Potsdam, 1916-27

by Q, those for international disturbed days by D, and those for medium days (all days except Q and D days) by M. For clearness, only the point for Q is connected with the origin, and for the same reason Q, M, and D are connected by straight lines. The big seasonal change in the quiet-day diurnal variation makes it necessary to compare only days of the same season and to apply some sort of correction to common season as well as to common epoch in sunspot-cycle.

The information contained in this diagram may not be discussed here in full, but the change from Q to D is marked, especially in the vertical component. Therefore, the change of the solar diurnal variation within the sunspot-period, as studied in most of the former work, is complicated by a simultaneous change in the relative contributions of Q and D to the whole variation. The same is valid for the well-known comprehensive decomposition of the diurnal variation into two parts, one independent of the sunspot-number, the other proportional to it (see Ad. Schmidt, Archiv des Erdmagnetismus, Heft 1-4, Potsdam).

3--Consideration of this kind caused S. Chapman and J. M. Stagg (Proc. Roy. Soc. London, A, v. 123, 28, 1929, and v. 130, 668, 1931) to select the very quiet days with international magnetic character-figure 0.0 and 0.1. As an index for the intensity of the solar diurnal variation S_q, they used the range, that is, the difference between the maximum and minimum, for each day and element separately. They found a considerable variability, with an average departure of 20 to 30 per cent from the range normal for season and sunspot-number. There is a definite correlation between the changes in different elements and at different stations. Discussion of this relationship shows that it is due partly to some world-wide cause (probably the solar ionising-agency Q) and partly to regional causes; the latter are assumed to be terrestrial, while the idea of regional infection of the atmosphere by solar particles is discarded, perhaps too soon.

4--Now the range is a rather deficient characteristic of the solar diurnal-variation S_q, and its use is suggested mainly for the economy in computational work. It is proposed, therefore, to apply harmonic analysis, provided that the calculation is cut down by the use of differences between successive bi-hourly values (see Beitr. z. Geophysik, v. 28, 1, 1930).

If J harmonics are calculated, that is, 2J harmonic constants a_j, b_j in the expression

$$\sum_{j=1}^{J} (a_j \cos jt + b_j \sin jt)$$

(where t is local time), each day is described by the 6J constants for the three components X, Y, and Z of magnetic force observed at a certain station. If the number of observatories involved is K, say, the interval of 24 hours from Greenwich midnight to midnight is characterized by T = 6JK harmonic constants. The question is, how to use these data for judging the varying intensity or shape of the diurnal magnetic field.

5--The ideal process would be to analyze a great number (say N) of these very quiet days. In a space of T dimensions corresponding to

$$a_j (X, k),\ b_j (X, k);\ a_j (Y, k),\ b_j (Y, k);\ a_j (Z, k),\ b_j (Z, k)$$

for values of j from 1 to J, of k from 1 to K, each day (with the index n = 1, 2, ...N) are represented by a point P, or better the vector OP_n drawn from the origin. N days are represented by as many points, and their geometrical distribution is a suitable and comprehensive substitute for the original magnetic data. If the points are regarded as equally loaded with mass, their center of gravity C gives the average S_q. The line CL of closest fit to the n points in this "generalized harmonic dial" coincides with the greatest axis of the so-called correlation-ellipsoid (see K. Pearson, Phil. Mag., London, series 6, v. 2, 559, 1901); indeed the whole set of equations derived for multiple correlation between T variables can be readily applied and interpreted in a physical meaning. The generalized direction-cosines β_1, β_2, ... β_T of CL would indicate the average tendency of the world-wide changes of the diurnal field. The departure of S_q (n), on a single day, from the average S_q is given by the vector connecting C and P_n.

P_n' may be the foot of the line drawn from P_n perpendicular to CL (Fig. 2). Then CP_n is resolved into two components, one (CP_n') along, and the other $(P_n P_n')$ perpendicular to, CL; the meaning of this will be explained later (see section 7). It is a well-known property of a harmonic dial--inherent in the linearity of the formulae of harmonic analysis--that every vector, such as $P_n P_n'$, represents a set of T harmonic constants, which corresponds to the differences between the diurnal curves represented by P_n and P_n'.

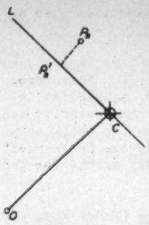


Fig. 2

6--CL has been chosen so that the sum of $\overline{P_n P_n'^2}$, taken over all days, is a minimum. The physical meaning of this geometrical construction may be interpreted by the following analogy: Consider a single diurnal curve for the northward component X, given in departures x_p (p = 1, 2, ... P) from the mean for the day. Then the mean-square departure is $x^2 = \sum_{p=1}^{P} x_p^2/P$. If a diurnal curve is calculated from the harmonic constants a_j, b_j, its mean-square ordinate is $\sum_{j=1}^{J} (a_j^2 + b_j^2)/2$. Now $m_x^2 = \overline{x^2} - \Sigma(a_j^2 + b_j^2)/2$ can be shown to be the mean-square difference between the given ordinate x_p and the calculated curve. The ordinary formulae for a_j, b_j make m_x^2, defined in the latter sense, as small as possible for any choice of a_j, b_j.

Suppose the magnetic force at a single station represented in ordinary three-dimensional space by a field-vector drawn from a fixed origin. Then the observed diurnal variation of the three components X, Y, Z can be represented by one curve, described by the end F of this vector. Consider further the approximative curve, calculated from the a_j, b_j. The average square of the lengths of the difference-vectors drawn between simultaneous points of both curves is $m_x^2 + m_y^2 + m_z^2$, a minimum. If M is the end of the vector representing the mean of the day, then the mean value of MF^2 is $\Sigma(a_j^2 + b_j^2)/2$, summed over X, Y, Z, and j = 1 ...J. This has a simple geometrical meaning, but, of course, must not be mistaken for an expression for the magnetic energy.

7--If J is big enough, the m's can be neglected. Then each diurnal curve is fully replaced by the harmonic constants a_j, b_j, and the T-dimensional harmonic dial is a comprehensive representation of the diurnal variation at all stations involved.

The geometric construction can now be translated as follows: The diurnal variation S_q for every day is resolved into three parts. The first (Fig. 2) is the average variation $OP_n = OC + CP_n' + P_n' P_n$. The second part can be written $CP_n' = q_n \cdot CL_1$, where CL_1 is the vector of unit length along the line CL of closest fit, and q_n is presumably an approximate index for the world-wide influence of the solar ionizing-agency Q. The third part $P_n' P_n$ is a representation of the regional, ephemeral changes. The separation, indeed the definition, of "world-wide" and "regional" changes by assigning all systematic changes to the former, all irregular changes to the latter, making these as small as possible, is of course arbitrary, but seems reasonable.

Referring to the set q of diurnal curves (K in number) which are described by the ends of the three-dimensional field-vectors F, the T-dimensional vector OC represents the set of average curves, OP_n the set of curves for a single day, CP_n the set of curves for the departures from the average curves. CP_n is the sum of two sets of curves, of which one (CP_n') has always the shape given by CL_1, and varies from day to day only in intensity; the other set $(P_n P_n')$ is irregular and, because of the choice of CL, as small as possible in the average taken over all stations and all days.

For large departures of Q from the mean, the relation between OP_n and Q may no more be linear, but preliminary calculations tend to show that a linear formula will go far in representing the systematic variability of S_q.

8--Many lines for physical interpretation are easily suggested. One of the principal questions will be, whether CL has the same direction as OC or not, that is, whether the variability of Q affects merely the intensity, or also the shape of the diurnal field S_q, and if so, in what way. The correlation of q_n with solar phenomena will be important. The discussion will, analogous to that of Chapman and Stagg (l.c. p. 875), start from the formal representation of the external diurnal field by electric currents in the high atmosphere, and judge the possible distortion or displacement of the current-lines. Further points to be discussed will be the remarkable dependence of S_q on the daily mean and on the non-cyclic change, as well as the correlation between S_q on successive days found by these authors.

9--All the calculations mentioned above tend only to give a comprehensive representation of the quiet-day diurnal variation S_q all over the globe. They are to be regarded, so to say, as one of the intermediate stages on the way from the observations to physical theory, characteristic for geophysical work. They are unbiased by any hypothesis. It is perhaps an advantage that spherical harmonic analysis and separation of the exterior and interior field does not come in at the outset, but, of course, both can be introduced at any stage of the work.

In order to keep the computations within reasonable limits, several simplifications will be necessary. The general case, involving the harmonic constants of several stations in one calculation, was outlined to show the scope of the method. In practice, the number J of sine-waves need not be greater than 2 or 3. Separate lines of closest fit will be found first for single stations or even magnetic elements. These results, combined for several stations, will make possible the separation into the two parts of the variability.

10--It is of advantage to take groups of days which are sufficiently uniform with regard to season and sunspot-cycle. Otherwise, some kind of reduction to uniform conditions can easily be effected, as, for example, in the work of Chapman and Stagg.

The method will give satisfactory results only for accurate observations. An uncorrected residual of temperature-variation in the records of the intensity-variometers would vitiate especially the 24-hourly wave because the temperature-insulation of the observatory, in reducing the outdoor temperature-variation, will be less effective in that wave than in waves of shorter periods. On the other hand, a comparison of the magnetic sine-waves with weather-conditions at the same station will yield a good test for the reliability of the records. This may be of value in connection with the fact that the diurnal variation is more irregular in those components possibly affected by temperature-variations (X, Z) than in Y (Handbuch d. Experimentalphysik, v. 25, Part 1, 468, Leipzig, 1928). If a spurious effect is found, it could be eliminated; it is not impossible that some of the larger "residuals" (differences between observed harmonic constants and spherical harmonic analysis) may be reduced.

The non-uniform distribution of observatories can be taken into account by giving to each station a suitable weight, according to the portion of the Earth's surface which it is to represent.

11--So far relatively few calculations have been made. With regard to the announced polar year, two harmonic dials have been drawn for Sitka, horizontal intensity, 24-hourly wave (Fig. 3). Each point represents an interval of a very quiet Greenwich day (international character-figure 0.0 or 0.1): its rectangular coordinates are the harmonic constants a_1 (upwards) and b_1 (to the right) corrected for non-cyclic change. Its distance from the origin is the amplitude. The occurrence of maximum, according to local time, can be taken from the dial, just as in Figure 1. The days are taken from the months May, June, July, 1907-22. Two groups of years were formed according to solar activity; the average sunspot-number for 1907 to 1909, 1915 to 1921 (maximum years) is 56, and for 1911 to 1914 and 1922 (minimum years) is 7; the number of days available is 151 in the maximum years, 110 in the minimum years. The seasonal difference between the three months, though small, has been eliminated.

In both groups, the average sine-wave has its crest about one hour after local midnight; the phase-angle $a_1 [\ln c_1 \cdot \sin (t + a_1)]$ is 70?1 (maximum years) and 75?8 (minimum years). The amplitude c_1 is 13.5γ and 9.7γ, respectively.

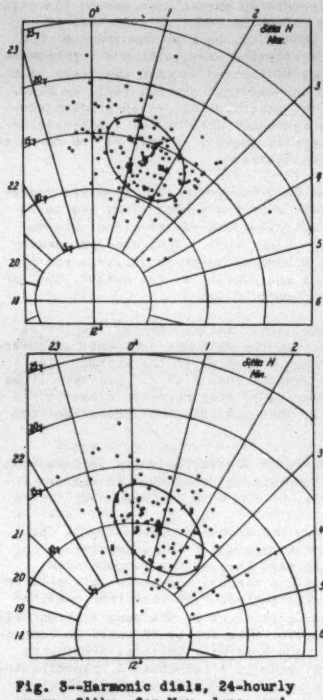


Fig. 3--Harmonic dials, 24-hourly wave, Sitka, for May, June, and July, 1907-22

The distribution of points is summarized by the "probable ellipse," containing half of the points, and indicating, by its great axis, the line of closest fit. In the maximum years, the great axis is 1.46 times greater than the small axis; in the minimum years, this ratio is 1.65. This ratio is also that of the mean-square deviation of the points parallel and perpendicular to the line of closest fit; details will be given in a later paper.

The great axis does not fall into the direction of the average vector, nor into the line connecting the centers for minimum and maximum years, nor into the direction of the variation on disturbed days, which would be parallel to the 16^h line on the dial (as judged from S. Chapman, Proc. Roy. Soc. London, A, v. 115,244, 1927). This strongly indicates an individual change in the shape of the diurnal field near Sitka. Faulty influence of temperature is highly improbable under conditions of observation at Sitka; the H-variometer has a temperature-coefficient of 7γ per degree C, and the whole diurnal variation of temperature inside the building, inclusive of the progressive change, is only a few tenths of a degree.

12--Whether this change of the sine-wave is a pure effect of the Q-radiation, remains uncertain at this moment. For the possibility, that D-radiation occurs sometimes on magnetically quiet days, is pointed out again recently by the occasional visibility of auroral rays on such days (Naturw., v. 19, 190-191, 1931). Near the auroral zone, the magnetic field will be especially sensitive to D-radiation; so, the magnetic records of the forthcoming polar year would give valuable material for an investigation of this kind, provided that not the slightest faulty temperature-variation vitiates them.

In a random-distribution, the probable ellipse would degenerate into a circle. So, the marked ellipticity found in the Sitka harmonic dial seems to represent an essential feature in the diurnal variation, and gives room for the hope that the process proposed in this paper will give new results regarding the variability of the Sun's radiation. To what extent the program will be carried out, is mainly a question of computational assistance, for the amount of data available is great.

So far, magnetic records are unique among the geophysical observations which give information on the state of the upper atmosphere and its relations to the Sun, because they have been taken systematically for many years at stations all over the globe. Therefore, it appears that this additional computational labor required may be justified; though this labor may seem large, it is indeed small compared with the amount of work spent on the maintenance of the observatories and the usual reduction of their records.

Radio research will be a useful supplement; but apart from indicating the height and constitution of the ionized layer, it will perhaps be a long time before such research can provide an estimate of the average state and the changes of ionization over a considerable range of height and horizontal extent in the atmosphere, as magnetic data do.

In conclusion, I wish to express my thanks to the Notgemeinschaft der Deutschen Wissenschaft, Berlin, for a grant covering computing assistance and to the United States Coast and Geodetic Survey, Washington, D. C., for a complete set of the yearbooks of the observatories. The next station to be investigated will be Watheroo, which is of special interest because of its situation in the southern focus of the diurnal magnetic field.

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THE ELECTRICAL STATE OF THE SUN

Ross Gunn

(Abstract)

The magnetic field due to the rotation of our galaxy is calculated, and it is shown (a) that electricity cannot be annihilated in the sun or stars; (b) that the net electrical charge on the sun or a typical star cannot exceed 1 coulomb. The electric fields, space-charge, and potentials of the solar atmosphere are calculated from data relating to the solar anomalous rotation and numerical values given. The negative surface charge on the sun is calculated to be of the order of 10^9 e.m.u. The problem of the maintenance of the solar electric field is touched upon. (The paper is published in full in Phys. Rev., v. 37, 983-989, April 15, 1931.)

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THE ULTRAVIOLET-LIGHT THEORY OF COMET-ACTIVITY

H. B. Maris

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The recent study by Hulburt and Maris (Phys. Rev., v. 33, 1046-1060, 1929) of the relation between comet-activity and terrestrial magnetic storms omitted the 1835 appearance of Halley's Comet, the great comets of 1843 and 1847, and the breaking up of Biela's Comet of 1846 because no magnetic storm-lists were available for years earlier than 1848. A storm-list compiled from the records of Gauss's (Gauss, Werke, 1867) studies at Göttingen (Beobachtungen des Magnetischen Vereins, Gauss und Weber, 1836-1841) and from the hourly observations at Prague (Reports of the Magnetic Observatory at Prague, 1836-1847) shows that in each case extraordinary comet-activity was preceded by the greatest magnetic disturbance of the year. The time-intervals between the magnetic storms and the respective comet-events were 2, 11, 11, and 16 days, and in each case the comet was favorably placed to be in the path of the solar ultraviolet flare responsible for the terrestrial magnetic storm.

The 1835 appearance of Halley's Comet was marked by such violent activity that, quoting from Chambers (Story of the comets, p. 122, 1910), "Did the statements not emanate from some of the most distinguished astronomers of the times it might be permissible to distrust them." Peculiar activities described as similar to those of the aurora polaris were first observed October 10, 1835. Gauss (l.c., p. 567) records October 8, 1835, as giving the greatest agitation to the magnetic needle observed during his studies. At this time the comet was about one astronomical unit from the Sun and subtended an angle of about 20° with the Earth. Since the activity consisted principally in changes in the brightness of the atmosphere of the comet similar to the changes in brightness of the Earth's atmosphere during an auroral display, it seems reasonable to assume that the ultraviolet outburst on the Sun which caused the October 8 terrestrial storm started the comet-activity observed October 10. Arago (Oeuvres, 1854) describes a great magnetic storm and auroral display observed November 17 and 18, while Gauss describes great magnetic storms observed November 28 to 29 and January 30, 1836 (l.c., tables 4 and 5, 1836). Arago describes only one other storm, a small one, February 17, 1835, for the period 1832 to 1835, and Gauss no others. The excep-

tional activity of Halley's Comet was evidently associated with exceptionally active magnetic disturbances on the Earth throughout the period of observation.

The great comets of 1843 and 1847 were remarkably brilliant, being equalled or surpassed by only two other comets during the century. Since both were near the Sun at perihelian-passage it is difficult to estimate the importance of solar outbursts, but the comet of 1843 showed a stellar nucleus on March 7, eight days after perihelian-passage and eleven days after the largest magnetic disturbance of the year and the comet of 1847 was most brilliant at perihelian-passage eleven days after the greatest magnetic storm of the year. The angles subtended by these comets and the Earth at the times of the storms were approximately 40° and 90°. Since nearly all of the light of a comet comes from the coma or atmosphere, which stays with the comet for only a few days when near the Sun and may be greatly changed by the absorption of ultraviolet-light, far-reaching effects of a solar outburst would be expected.

November 28, 1846, Biela's (l.c., p. 15) comet was first observed as a faint nebulosity. December 19, the nucleus was seen to be dividing and division was complete by December 31. The comet appeared during unusually quiet magnetic weather but there was a great storm December 3, sixteen days before the nucleus was seen to be dividing. This was the only disturbance between the preceding March and the following August when small storms were recorded. December 3, the comet was 1.5 astronomical units from the Sun and subtended an angle of 30° with the Earth. It seems probable that the ultraviolet solar outburst which caused the storm of December 3 also caused the formation of the new nucleus. Biela's Comet was approaching the Sun when it was broken up. The new nucleus was driven back and away from the Sun, dropped into a shorter-period orbit in the original plane and was leading the original comet on the next return to perihelian. The disrupting force was a repulsion from the Sun. Light-pressure is considered to be the most probable source of this force. The atmosphere of a comet is transparent to visible light but, it is assumed, strongly absorbs ultraviolet radiation which, because of this absorption, exerts a pressure upon it. During a solar outburst the intensity of the ultraviolet radiation and consequently of light-pressure on a comet's atmosphere may increase a thousand fold or more (l.c., p. 423). A wind created by such a pressure is assumed to have swept part of the nucleus of Biela's Comet away with it. This nuclear material, after the outburst had passed, collected under its own gravitational field to form a new nucleus. This is contrary to the suggestion of Jeans (The universe around us, p. 244, 1929), who assumes that tidal action provided the separating force and cites, in addition to Biela's Comet. Taylor's Comet of 1916, and the great comet of 1882. Taylor's Comet was about two astronomical units from the Sun at the time of its disruption, even farther than Biela's Comet, and tidal action could not have caused it to break up, but it, like Biela's Comet, met a very active Sun (l.c., p. 1057) as is shown by the records of magnetic storms on the Earth. The great comet of 1882 made a close approach to the Sun and might have been broken up by tides, but the great comets of 1843 and 1880 made closer approaches to the Sun without being broken up. The respective perihelian-distances were 0.008, 0.0055, and 0.0069. On the other hand, the great comet of 1882 at the time of its approach met a tremendous solar disturbance which was recorded on the Earth as one of the greatest magnetic storms of all times (l.c., p. 1051). Obviously this solar disturbance may have been the cause of disruption of the comet.

The comet-events of the period 1835 to 1847 give surprisingly strong support to the theory that comet-activity is similar to aurora polaris and that most irregularities in comet-activity are caused by irregularities in solar ultraviolet radiation.

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MAGNETIC OBSERVATIONS ON A MOVING ICE-FLOE

W. J. Peters

Magnetic observations on the arctic ice-floe are made under two unique and desirable conditions. The magnetic material of the Earth is on the average some 4,000 feet below the observer. His observations should, therefore, give a fair representation of the Earth's field at the time of observation undisturbed by local anomalies,

excepting of course the case of a high submarine peak or ridge directly below him. The motion of the floe or pan on which observations are made is so slow that individual readings can be made with as much deliberation and with the same accuracy as on land.

It seems desirable, therefore, to consider the magnitude of the motion and any other unfavorable condition peculiar to the ice-field with a view to eliminating them by methods of observation or the application of corrections.

The motion of the polar ice-field is a combination of translation and rotation, usually termed drift and screwing or twisting. Information regarding the speed of these motions is rather meager, but that which is available indicates that both drift and twisting are very irregular.

The track-chart of the Fram for the three years 1893-1896 (F. Nansen, The Norwegian North Polar Expedition 1893-1896, Scientific results, v. 2, 1901), during which she was locked in the polar ice-field gives her position at intervals of one to five days. The time is given to the nearest tenth of an hour so that the average velocity for any one interval can be computed with considerable accuracy. A selection of a few of the greatest velocities shows that a maximum average hourly velocity of one-third mile was not unusual.

We are interested, however, in the maximum drift that can occur between two sets of solar observations made some six hours apart for position. The track-chart of the Fram shows the drift to be very irregular both as to velocity and direction. It is, therefore, conceivable that the actual drift during six hours, for example, between solar observations for position might be much greater than six times the average hourly velocity deduced from intervals of several days' duration. The error of position considered spatially is not so important as the resulting error of longitude which will appear in time-azimuths of the Sun.

Information about the amount and speed of twisting of the ice-field or individual pans is less adequate. A single set of observations of the Ziegler Polar Expedition 1903-1905 (The Ziegler Polar Expedition 1903-1905, Scientific results, 359, 1907) showed that the twisting fluctuated between 1 and 3.5 minutes of arc in one minute of time during an interval of $1^h\ 40^m$ and that the total change amounted to 4° during this interval. These observations were made when the vessel was locked in the floe south of Franz Josef Land.

No especial observations for the determination of floe-motion appear in the published magnetic results of the Fram Expedition, but an examination of the astronomic observations which are given in considerable detail indicates that twisting motion did exist, although no set or sets of these observations show as great a rate or as great an amount as was found on the Ziegler Expedition. A total amount of 27' in 56 minutes of time or an average 0.4 to one minute of time is indicated. There may be cases, however, when it was greater, but they do not appear to be frequent.

In view of the paucity of magnetic data over the regions of the polar ice-floe, even rough approximations of the elements are desired. But when accurate determinations are practical the effect of floe-motion should not be overlooked.

Besides the effect of motion of the ice, there are notably large time-fluctuations in the polar regions. These may be large enough occasionally to mask the effects of floe-motion while observations are being made. During the proposed International Polar Year, however, the records of many polar stations will serve to verify their existence at least and possibly to furnish corrections in the final computations. In the absence of such records there appears to be available only the prolonging of observations in the expectation that the fluctuation-effects in a mean will diminish as the interval for which the mean is taken increases.

It is inexpedient to discuss details of methods here. The ingenuity of the observer will devise them once he realizes the existence, magnitude, and irregularities of the motion of the ice. It might be pointed out, however, that continuous observations for Sun azimuths contemporaneous with magnetic declination using two instruments that may be mutually collimated will serve to eliminate twisting-effects in declination. Declinations obtained with a ship's compass are free from floe-twisting errors

and this compass is also suitable for observing the twisting for the purpose of controlling the meridian-readings of the dip circle.

Determination or elimination of drifting-motion is generally more unsatisfactory. Fortunately it is small. If stars can be observed, the problem is simple. Simultaneous altitudes of two stars or altitudes symmetrically grouped about their time-means and differing some 90° in azimuth will give the geographic position at the instant of their time-means. If their time-means correspond to the time-mean of the magnetic declination, the time-azimuths will be adequately controlled. If two sets are taken some hours apart, the drift during the interval may be calculated. If only solar observations are available, there appears no very satisfactory method of correcting the errors produced by drifting.

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ISOMAGNETIC CHARTS OF THE ARCTIC AREA

Harlan W. Fisk

In view of the activity in arctic research promised for the coming season and for the proposed polar year, the preparation of preliminary isomagnetic charts of the area about the north pole, including the Arctic Sea, and the margins of the land immediately adjacent was undertaken.

The following sources of information were utilized: Curves of equal magnetic variation for 1927 (British Admiralty chart No. 2598); the magnetic inclination or dip for 1930 (H.O. chart 1700); the horizontal intensity of the Earth's magnetic force for 1930 (H.O. chart 1701); magnetic meridians and curves of equal magnetic variation for 1922 in the arctic regions, by H. Spencer Jones (Geographical Journal, December 1923); United States magnetic tables and magnetic charts for 1925, by Daniel L. Hazard (Coast and Geodetic Survey, serial No. 453); lines of equal declination, lines of equal inclination, lines of equal horizontal intensity, and lines of equal vertical intensity for Alaska, furnished in manuscript in advance of publication by courtesy of the Director of the Coast and Geodetic Survey; lines of equal magnetic declination and lines of equal annual change in Canada for 1927; lines of equal magnetic dip and annual change in Canada for 1927; lines of equal magnetic horizontal intensity in western Canada for 1922.0 and lines of equal annual change between 1917 and 1922 (charts of the Topographical Survey of Canada); catalog of magnetic determinations in U.S.S.R. and adjacent countries from 1556 to 1926, prepared by B. P. Weinberg, Leningrad, 1929; magnetic general chart of Sweden, 1930, by Gustav S. Lungdahl, Stockholm; chart of magnetic declination in the European part of the U.S.S.R. reduced to epoch 1925, by N. Rose, Leningrad, 1925; Atlas des Erdmagnetismus, by Georg Neumayer, Gotha, 1891; Volumes I to VI, Researches of the Department of Terrestrial Magnetism, Carnegie Institution of Washington; world magnetic data (unpublished), by W. J. Peters; magnetic results obtained at Spitzbergen by the Citta di Milano Expedition; results of Cruise VII of the Carnegie in the vicinity of Iceland.

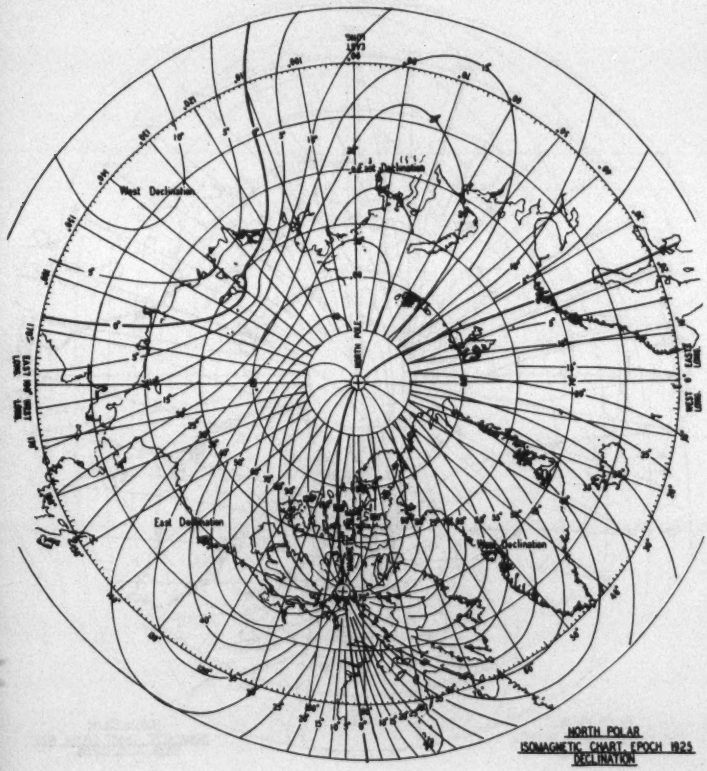
Most of the data used in compiling these charts are comparatively recent. In some cases results obtained by compilers who have assumed rates of secular change by means of which corresponding values for a later epoch have been derived have been utilized. Where unreduced values have been utilized, only those from observations subsequent to 1900 have been accepted. Compilers have not been in agreement as to the secular changes taking place over the area and consequently there are many inconsistencies that must be adjusted. The charts are necessarily, therefore, the results of compromise.

Isogonic chart--lines of equal declination--Since declination at a given point is defined as the angle between the geographic and the magnetic meridian, it follows that all isogonics must pass through the magnetic pole where the magnetic meridians converge, and similarly they must pass through the geographic pole where the geographic meridians converge. This condition produces a pattern of lines which restricts

the practical usefulness of the chart in the vicinity of either pole, and adds greatly to the difficulty of drawing the lines accurately. Some assistance may be derived by referring to a chart showing the magnetic meridians in attempting to use a compass in the vicinity of the geographic north pole.

Magnetic meridians--The curvature of these lines is much smaller than that of the isogonics, and they are, therefore, simpler to delineate. Their advantage lies in the fact that they indicate directly the portion of the surrounding lands toward which the compass may point at any locality.

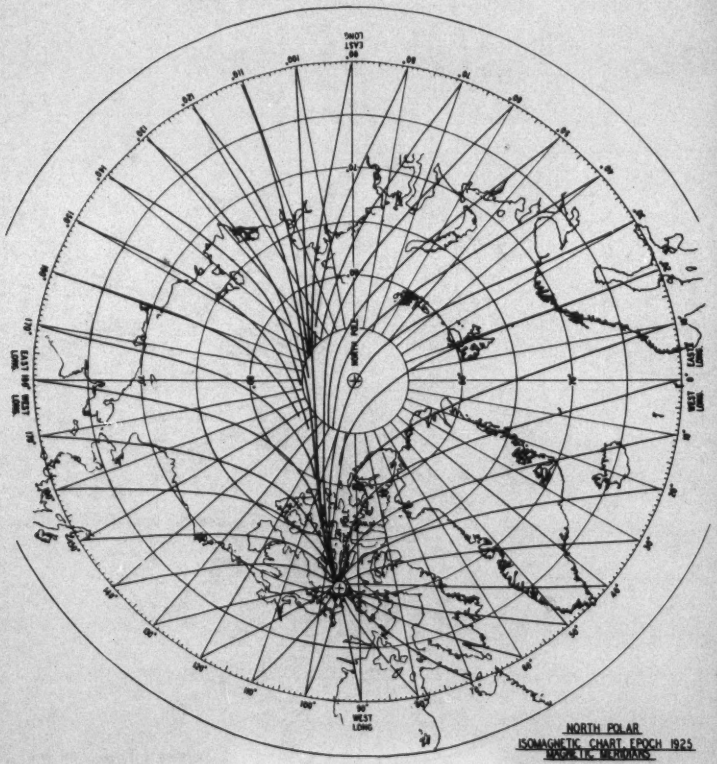
Isoclinic chart--lines of equal dip or inclination--The magnetic pole is taken to be the region within which the horizontal component vanishes and the inclination becomes vertical, while the compass-direction is indeterminate. Two determinations of the location of the north magnetic pole have been made, that of Ross in 1831, and that of Amundsen in 1903-1904. The Amundsen position is shown on these charts, although it will be observed that it does not lie symmetrically within the lines of equal values of the elements. The position generally accepted for the Amundsen determination is 70° 30' north latitude and 95°30' west longitude.



NORTH POLAR
ISOMAGNETIC CHART, EPOCH 1925
DECLINATION

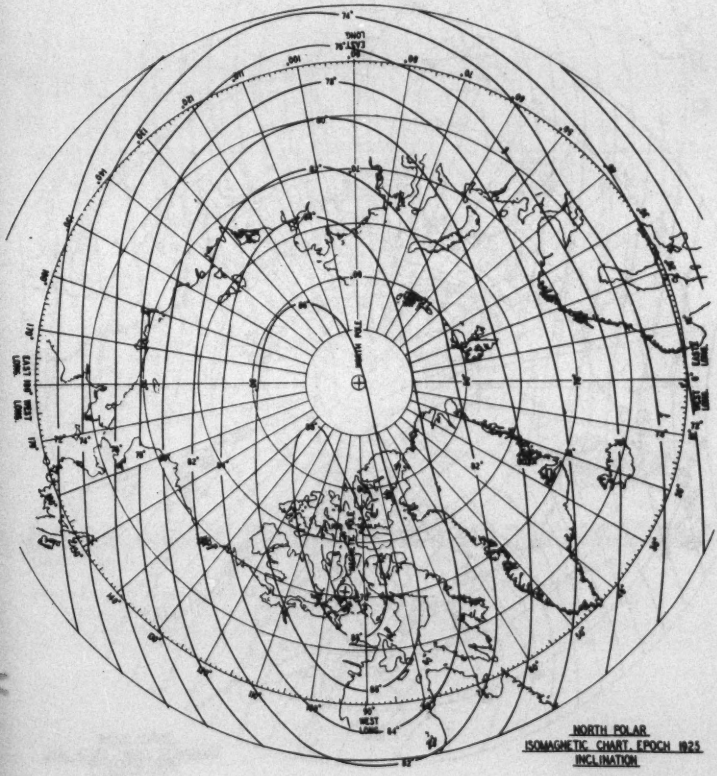
The oval extension of the lines in the direction of the Siberian coast is one of the puzzling facts to be accounted for, but is well substantiated by the results of both the Fram and the Maud expeditions. It may be of interest to note that the great-circle plane including both magnetic poles cuts across this area nearly at right-angles to the general direction of the axis of these ovals, that is, it passes northeastward below Cape York, Greenland, and strikes the European coast near Bergen, Norway, and its extension in the opposite direction leaves the American continent near the upper end of Vancouver Island.

Isodynamic charts--lines of equal total intensity--Practice has varied in arctic magnetic surveys; sometimes the elements determined were the inclination and total intensity, using the dip circle for both, and deriving the horizontal component by computation; and others, notably the Fram Expedition, have determined the horizontal component by means of a magnetometer, depending upon computation for the total force. Obviously the former method is most advantageous where the horizontal force approaches zero and the secant of the inclination, which must be used in the computation of total force, increases very rapidly, approaching infinity near the magnetic pole. Published



NORTH POLAR
ISOMAGNETIC CHART, EPOCH 1925
MAGNETIC MERIDIANS

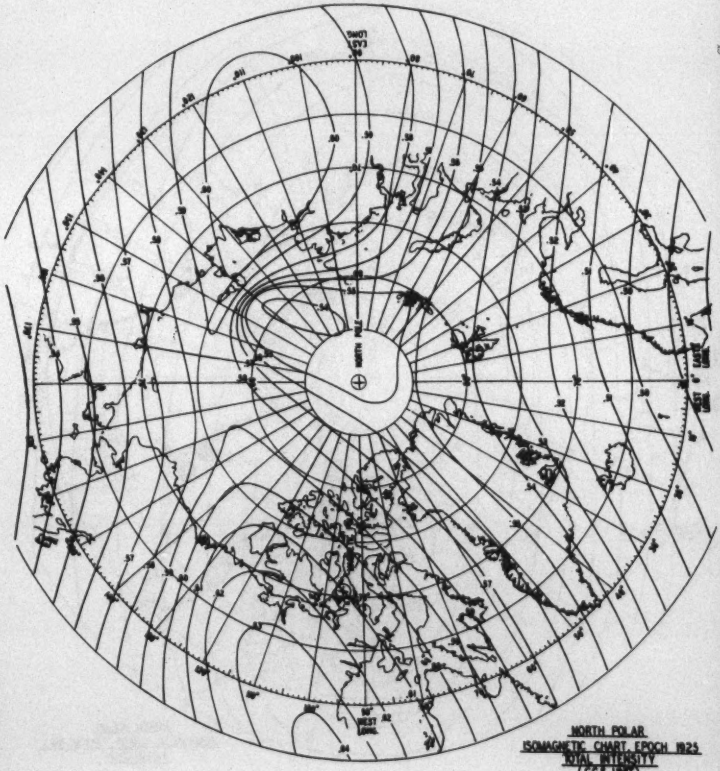
data generally include the inclination and the horizontal component, so that charts of those two elements were first prepared, with the intention of using the values scaled from these for constructing the total-intensity chart. The method was found quite impracticable since inevitable inaccuracies involved in scaling from smoothed curves resulted in improbable irregularities in the distribution of total intensity. It was necessary, therefore, to compute a value of the total intensity for each of the stations utilized in the work, and make the chart conform to those results. The irregular feature shown near the geographical pole results from the series of values obtained by the Fram in 1893-1896, and those of the Maud 1922-1925. The results of both expeditions are as reliable as any observations are likely to be in the arctic and seem to indicate a great regional anomaly. The secular change in the interval between the expeditions is uncertain but is believed to be relatively small, and not such as to materially alter the general pattern of the lines. It is also of interest to note that in the "Atlas des Erdmagnetismus" prepared by Georg Neumayer and published in 1891, before the work of Nansen, Amundsen, Sverdrup, or of any of the recent expeditions had been done, there is a small chart of total intensity



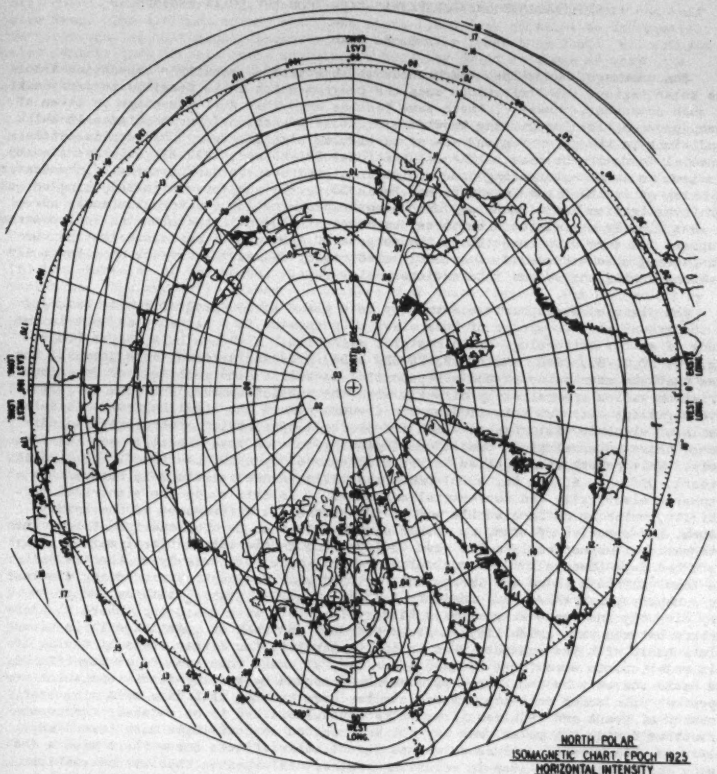
which shows the general distribution quite similar to that given here, that is, areas of high total force in Canada and Siberia, with an intervening low area embracing the north pole. That chart was prepared from an analytical consideration of the results of the polar-year stations, 1882-1883, such other meager information as was then available, and harmonic analysis of the Earth's field.

Isodynamic chart--lines of equal horizontal intensity--After the completion of the inclination- and total-intensity charts, the horizontal-intensity chart was redrawn in order to secure mutual consistency among the related components. The necessary adjustments and smoothing of irregularities have doubtless created departure in some places from the positions of corresponding lines determined in other compilations. One feature of this chart deserves particular mention. It will be noticed that the horizontal intensity upon which the action of a compass depends is very weak over a large area, extending in a narrow belt clear across the Arctic Ocean.

Notwithstanding the meagerness of the data, it is believed that the facts are reasonably well represented by this chart and the others of the series, and that



NORTH POLAR
ISOMAGNETIC CHART EPOCH 1925
HYAL INTENSITY
(C.G.S. UNIT)



NORTH POLAR
ISOMAGNETIC CHART, EPOCH 1925
HORIZONTAL INTENSITY
(C.G.S. UNIT)

they present a picture of magnetic distribution that may serve as a preliminary basis upon which a more accurate series may be constructed as the essential facts become better known.

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SIGNIFICANCE OF GEOELECTRIC DATA FROM THE POLAR REGIONS

O. H. Gish

The expenses, hardships, and hazards which attend a scientific expedition into the polar regions set limitations upon the program which it is feasible to carry out on such occasions. However, these same factors urge that full advantage be taken of such opportunities for gaining knowledge of those branches of Earth science in which conditions in the polar regions are of particular significance. This applies with especial force in the case of the International Polar Year, 1932-33, which as planned promises to be an outstanding case of international cooperation in scientific endeavor In this, as in the first International Polar Year, the subjects definitely singled out for investigation are meteorology and terrestrial magnetism. Other phenomena, more or less closely associated with these, have been included in the observational program proposed for some stations. It is the purpose of this paper to present reasons for considering observations of atmospheric electricity and earth-currents at a few polar stations during the second International Polar Year.

The claim of atmospheric electricity to a place on the program cannot be urged on the ground that knowledge of this class of phenomena is a valuable adjunct in the study of either meteorology or terrestrial magnetism. Although L. A. Bauer (Terr. Mag., v. 27, 1-30, 1922, and v. 29, 23-32, 1924) presents evidence in support of the view that the mean value of the air-potential as well as the amplitude of the diurnal variation varies approximately directly with the sunspot-number, yet even if further investigations bear out this finding there would remain the likelihood that it is the result of electric disturbances which are produced by certain meteorological conditions, these meteorological conditions depending more or less directly upon solar aspects. This remark also applies to results reported by A. W. Lee (Prof. Notes, Brit. Meteorl. Off., v. 4, No. 58, 1930) under the title "A new relationship between atmospheric electricity and terrestrial magnetism." In this study the electrical variability, which he defines as the sum of the successive differences of the hourly values, irrespective of sign, is worked up for data from Lerwick and from Kew on the international magnetically quiet days (Q-days) and on the international magnetically disturbed days (D-days). His conclusions, which apply particularly to the Kew data, are that "although there are irregularities from year to year . . . . during the last two sunspot-cycles there is a tendency for the electrical variability on D-days to vary directly and for that on Q-days to vary inversely with sunspots," where the difference between the variability on disturbed days and that on quiet days is in closer relationship with the sunspots than is the variability for either class of days. If this relationship were found to hold generally, it would then seem to be significant and could scarcely be considered as a result produced by weather-conditions which are dependent upon solar activity. These studies seem to show that data extending over a number of years are required if definite conclusions are to be reached. Hence observations during the polar year may not be expected to contribute much toward an answer to this question unless perchance direct solar effects occur there with a frequency and intensity greater in relation to other disturbances than at the stations to which the studies of Bauer and of Lee apply. The available evidence bearing on this possibility is inconclusive.

It has been surmised in the past that polar lights may exert an appreciable influence upon the electric field in the atmosphere near the Earth's surface. However, the reports of those who have carried out simultaneous observations of both polar lights and air-potential are not unanimous. Some claim to have observed a close correspondence between auroral displays and changes in air-potential while others find no such relationship. H. U. Sverdrup (Res. Dept. Terr. Mag., v. VI, 458-459, 1927) on the basis of the excellent series of observations made during the Maud Expedition, 1918-25, concludes that "no relation exists between the minor disturbances of atmospheric potential-gradient and the auroral displays, but that an increase of the intensity of the aurora appears to be accompanied by a decrease of both value and diurnal range of the potential gradient." He points out, however, that the latter part of this conclusion requires confirmation. These divergent reports may signify that this relationship is found only in certain magnetic latitudes or at spots which are in some way especially favored and possibly even then only in connection with certain auroral types. One would expect to observe electrical effects in cases like that reported by J. H. Johnson (Concerning the aurora borealis, San Mateo, Califor-

nia) where "dancing streamers" were seen between the observer and a bluff one-half mile away. The altitude of the bluff was about 1,200 feet relative to the general surroundings, so that these streamers were apparently lower than that. Mr. Johnson also reports that in this case "there was a swishing sound at times as they (the streamers) moved." Perhaps this is an electrical phenomenon which is quite unrelated to the aurora.

While all these matters should be kept in mind in connection with any atmospheric-electric work in the polar regions, yet the claim of atmospheric electricity to a place on the program of the International Polar Year seems to rest principally upon the worth of such work in the solution of the problems of atmospheric electricity and upon the fact that the meteorological data obtained at this time will be a great aid in the elucidation of the electric phenomena. Problems whose solution such data will further are chiefly those for which the present data are inadequate, especially in respect to distribution in latitude. Two specific problems of this type are: (a) The character of the variation, if any, of the potential gradient with latitude, and (b) the character of the annual variation in both the mean gradient and its diurnal variation. The available evidence indicates that these features are influenced by cosmic or world-wide factors which may also come into account in other geophysical phenomena.

The only atmospheric-electric element which has been registered in high latitudes is air-potential. This because all things considered it is the easiest. It is, however, hoped that during the second polar year it will be possible to also register air-conductivity and to make manual observations of ionic density, of penetrating-radiation, of the radioactive-content of the air, of condensation-nuclei, and as many as possible of the other factors which affect the electrical state of the atmosphere. With such a program the interpretation could be carried much further than in cases where only one or two elements are measured.

When we come to consider the claims of earth-currents, the circumstances are different. Registrations of this at some polar-year stations may be urged not alone in its own right as a world-wide phenomenon but also because of the intimate interrelationship between earth-currents and the changes in the Earth's magnetism. Furthermore, such measurements are relatively simple and the equipment is inexpensive. From Chapman's general analysis of the diurnal variation in the Earth's magnetic field (Phil. Trans. Ser. A, v. 218, 1-118, 1919) it appears that on the average 28 per cent of this is due to electric currents in the Earth. Now, since the intensity and course of these currents in a given region will be influenced by the topography and structure of the region, there may thus arise appreciable anomalies in the magnetic variations. Registrations of earth-potentials should serve to detect such conditions and thus assist in the appraisal of variometer-data. Birkeland (Norwegian Aurora Polaris Expedition, 1902-1903, Second Section, v. 1, 736-741, 1913) even attempted to correct magnetic data on the basis of the earth-potential measurements. This, however, does not seem feasible except for special cases in which the conductivity and configuration of the distorting body is known. In the absence of anomalous structure, simultaneous measurements of the variations in the earth-currents and the Earth's magnetic field at a number of stations should provide a basis for deductions of broad significance to the theory of these variations and regarding the structure of the Earth.

Earth-current data from the frigid zone should help clarify the relationship which these bear to terrestrial magnetism. In lower latitudes the observed facts regarding diurnal variation in earth-currents are consistent with the conclusions derived from the general analysis of the magnetic diurnal variations, namely, that some system of electric currents, or an equivalent, in the high atmosphere is the primary cause of the magnetic variations and that the earth-currents are induced by the varying magnetic field. However, such data as are available from higher latitudes do not seem to fit into this scheme.

Another problem of special interest is presented by the relationship observed between the variations in earth-potentials and those in the magnetic elements at times of storm or other disturbances. The relationship which would be expected if the earth-current disturbances are produced by the magnetic disturbances seems to be the exception rather than the rule. The most commonly observed relationship is that which would

obtain if the earth-current variations were the primary source of the magnetic variation. Birkeland recognized this relationship and in attempting to explain it he assumed that in such cases the primary system is located in a restricted portion of the atmosphere over the poles. These he called polar storms. In other cases which were designated equatorial storms the primary system was located in the high equatorial atmosphere. Thus in the case of a polar storm the more intense disturbances, both in magnetism and earth-currents, would occur in high latitudes. Furthermore, the earth-currents here should have the characteristics of currents induced by the corresponding magnetic variations. These currents would, however, tend to spread throughout the Earth. In regions remote from the storm-center, the magnetic disturbances would then arise chiefly from these currents. This would be consistent with the relationship so frequently observed. Whether this is the true explanation would doubtless be definitely determined if earth-potential registrations made at a few polar stations are compared with simultaneous registrations obtained at the stations in lower latitudes. Such a decision would be so vital to the theory of magnetic storms that one cannot overemphasize the desirability of registering earth-potentials at a few polar stations.

In concluding, it is desired to point out a very suggestive feature which came to the writer's attention at the time of the magnetic storm beginning shortly after 21^{h} Greenwich mean time July 31, 1929 (Terr. Mag., v. 35, 113-114, 1930; Sci. Monthly, v. 32, 5-21, 1931). Earth-potential registrations for this storm were obtained at five widely distributed stations, two in the southern hemisphere (the Carnegie Institution observatories at Watheroo, Western Australia, and at Huancayo, Peru) and three in the northern hemisphere (Ebro Observatory, Tortosa, Spain; American Telephone and Telegraph Company station centering at New York, New York; and a station in the southern part of California). The comparison (made by W. J. Rooney and the writer) of these registrations revealed the surprising fact that at a number of times during this storm the earth-currents were flowing in nearly the same direction at all these stations. This was most strikingly shown in the case of the sudden initial pulse which was everywhere directed approximately northwest. Taking into account the wide distribution of the stations and other geophysical facts it has not been possible to devise a picture of this situation without doing violence to some fundamental aspects of theories of magnetic storms. In one conception which has occurred to the writer the initial pulse is made up of two components, one a ring-current flowing westward along the parallel of latitude, the other a current flowing northward along the meridian at each station. The first is readily accounted for by modern theories of magnetic storms, but no plausible mechanism that will account for the other has thus far been suggested. Further investigation of this feature is needed and to that end a wider distribution of data is required. It seems likely that data from the polar regions would be of especial value here as well as in the other specific problems which have been mentioned.

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A FORT CONGER POLAR-EXPEDITION PROGRAM

H. B. Maris

The following program has been prepared for the scientific activities of an observatory at Fort Conger, the station occupied in 1882 by General A. W. Greely, should means offer for its reoccupation in 1932-33 during the second International Polar Year.

Material should be taken for the construction of two observatories suitable for occupation throughout the period of the work. These buildings should be well built to provide a satisfactory housing for high-sensitivity instruments. The base of main observatory should be built on ground giving an unobstructed view of the horizon on Ellesmere Island to the west of Robeson Channel and as close to the Channel as possible. The second observatory should be located east of Robeson Channel on the Greenland ice-field at the greatest elevation visible from the base-observatory. Each building should be long enough to house a generator and radio transmitter at one end without interfering with magnetic instruments at the other end of the building. The central portion of each building should consist of a low two-story observatory, the

upper room of which would be octagonal with an observational window in each wall. Each window should be provided with triple sashes with plate-glass. The center of the ceiling of the room should be built for the mounting of a ten-inch helioscope. In addition to these permanent observatories there should be two temporary shelters for use during daylight.

The desirable scientific work may be divided into twelve projects under three general branches as listed below where the third column shows the place--the numbers 1, 2, 3, and 4 indicating the ship, the base-observatory, the ice-field observatory, and the temporary shelters, respectively--and the fourth column the time of the work.

Branch	Subject	Place	Time
Radio	(a) Communication	1	Day and night
	(b) Reflection	1,2	Day and night
Earth	(c) Magnetism	2,3,4	Day and night routine
	(d) Electricity	2	Day and night routine
	(e) Geology	2,3,4	Day
	(f) Biology	1,2,4	Day
Atmosphere	(g) Radiation	3	Night routine
	(h) Absorption	3	Night routine
	(i) Electricity	2,3	Day and night routine
	(j) Aurora	1,3	Night
	(k) Meteorology	1,3	Day and night routine
	(l) Balloons	1,3	Day and night routine

In addition to the above projects, attempts should be made to photograph artificial eclipses of the Sun, measure the thickness of the Greenland ice-cap and get photographs and spectra of astronomical objects through an atmosphere free of water vapor. The twelve projects listed above are discussed briefly in the following paragraphs.

(a) Radio communication--The ship should be made a center of communication for polar stations on the western hemisphere. Daily weather-reports should be transmitted when possible. A regular schedule of communication signal-intensity measurements should be followed.

(b) Radio reflections--Continuous records of reflection-layer heights should be made and a regular schedule of maximum density-measurements should be followed. Measurements of the density of the layer should provide ideal conditions for the recording of long time-echoes which might be observed.

(c) Earth magnetism--Standard equipment for the "polar-year observations" should be taken and routine records should be made at station 2. It would be desirable to supplement these records by others using a new type of instrument giving continuous record of field-changes in terms of two vectors instead of three (H, Z, and D). Records should also be made at stations 3 and 4. A comparison between the records of stations 2, 3, and 4 should give a measure of the electric current flowing in Robeson s Channel between Greenland and Ellesmere Island. Previous attempts to get a magnetic measurement of earth-currents have failed, but the quantity to be measured will be more than a thousand times as great in this case and positive results should be obtained.

(d) Earth electricity--Plans should be made to place electrodes in the water of the strait under the ice and make a direct measurement of electric currents in the sea-water. This has not been attempted before, but because of the peculiar position of Greenland and the narrowness of the strait, very large currents will flow and positive results should be expected.

(e) Geology and (f) Biology--During the spring and summer months all but routine care of instruments for other projects should be discontinued and interest should be centered on geological and biological studies. This would include location of control bench-marks, air-mapping, stratographic work in the United States and Garfield ranges, measurement of the thickness and motion of present glaciers and studies of past glaciation.

(g) Atmospheric radiation--Over most of the Earth the temperature of the air decreases with elevation, but this is not true in polar regions during the polar night. Measurements of night sky-radiation could be made quite easily and should tell something of temperature-changes in the upper atmosphere. It should be possible to detect radiation-changes associated with magnetic storms and auroral displays. The accuracy of the method is sufficient to indicate the changes expected. This work should be conducted principally at station 3.

(h) Atmospheric absorption--This would include routine measurements of ozone-absorption in the ultraviolet as a means of determining whether the ozone of the atmosphere is created at the pole or at the equator. If the ozone is formed at the equator and drifts to the poles during a winter-night the thickness will vary tremendously and may at times of high barometric pressure be reduced to practically nothing, leaving the air transparent in the ozone absorption-band. This work should be centered at station 3 and should require a ten-inch reflecting telescope. Such measurements should be of great value in determining the drift of air-currents from the pole to the equator or vice versa at great altitudes. Changes of ozone may be associated with magnetic storms and diurnal changes might be detected.

(i) Atmospheric electricity--Routine measurements of the potential gradient in the air should be planned for stations 3 and either 1 or 2.

(j) Aurora observations--The location near the center of the auroral region should give a good opportunity to determine any daily change of the aurora and two stations about 25 miles apart would be well located to determine heights. Routine observations should be made and there should be detailed comparisons between active auroral displays and atmospheric-electric changes.

(k) Meteorology--Routine records should be kept and daily reports made from stations 1 and 3.

(l) Meteorological balloons--Winds of the higher atmosphere should be studied by pilot- and sounding-balloons. Sounding-balloons should be sent up both day and night for temperature- and pressure-records which could be recorded by radio at station 1.

This program offers the following unique features designated according to the project involved:

(a) Daily routine meteorological reports for forecasting use
(b) Routine studies of maximum radio-frequency for vertical reflection; continuous record of reflection-layer height
(c) Magnetic measurements of earth-currents and a new type of magnetic record with a new type of magnetic instrument
(d) Earth-current measurements where the dimension of the conductor and the total current can be calculated
(g) Radiation-measurements for the polar-night sky
(h) Ozone-measurements during a polar night
(k) Establishment of a polar observatory at a great elevation
(l) Radio records from sounding-balloons for polar work

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AMERICAN GEOPHYSICAL UNION

Twelfth Annual Meeting

REPORTS AND PAPERS

S E C T I O N O F O C E A N O G R A P H Y

Washington, D. C.
April 30, 1931

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PROGRAM AND PROJECTS OF THE WOODS HOLE OCEANOGRAPHIC INSTITUTION

H. B. Bigelow

It is gratifying to be able to report to the Union that since our last meeting substantial progress has been made in the development of the Woods Hole Oceanographic Institution.

Shortly after the Institution received its endowment a year ago last February, work was started on the plans for the building at Woods Hole and for the research-ship. We were very fortunate in being able to secure from the Marine Biological Laboratory a convenient water-front site, where ground was broken last July. The building is now complete and will be ready to open its doors in June.

The main laboratory is a brick and concrete structure about 140 feet long by 50 feet deep, of the simple type of construction usual nowadays in laboratories. There is nothing especially startling about its design, for after all, the main requirements in an oceanographic laboratory are space in which to work and set up apparatus, with the necessary supply of water, electricity, and gas for the same. The aim in the present case is to supply facilities in whatever divisions of oceanography may be to the fore from time to time. Therefore, extreme specialization in the internal arrangement of the building was to be avoided. It is evident enough that chemical problems are now very pressing in the sea; consequently eight of the research-laboratories, besides one large room, are fitted with chemical hoods; most of the rooms have salt-water tables of the type now widely used in marine laboratories, on which small aquaria can be set up and on which experiments requiring sea-water may be carried on. There are also large aquaria-tanks in the basement. To meet the probable requirements of work in experimental oceanic biology, several of these tanks will be supplied with chilled salt-water so that cold-water animals can be kept alive through the summer season. We even have hope that we may be able to undertake physiological work on deep-sea forms by arranging to keep them under pressure. There is also a room in which constant temperature can be maintained, and likewise a special room for small refrigerators.

Deep-water animals are especially favorable subjects for experiments on light reactions and naturally the building contains experimental dark-rooms. On the other hand, several of the laboratories have been left bare of any special equipment for people who will be doing charting and computation in various fields of oceanic physics. Altogether there are 33 research-laboratories, large and small; and of course the usual machine-shop, storage-rooms, etc., in the basement; and finally the administrative offices.

About forty, or in a pinch fifty, investigators can be accommodated, and the Institution proposes always to hold several rooms free for visiting students.

Through the courtesy of the Marine Biological Laboratory, the staff and visitors to the Institution will enjoy the facilities of the very excellent library that the former maintains; consequently, it is not necessary for the Institution to have a library of its own. The library of the Marine Biological Laboratory already contains an excellent selection of the more important oceanographic titles and serials, and as the Institution has arranged to make an annual appropriation for the purchase of oceanographic books, this should soon develop into one of the more important libraries in this field. Naturally there will be a working collection of books in the Institution; there is also a fine chart-room and reading-room. One can suppose that before long a large number of charts will accumulate there.

I am sorry that we have no good photograph of the laboratory as yet. I have said all this about the building simply to let you know that the Institution is sure of comfortable and convenient shore-headquarters.

We are also very lucky in having deep-water right up to the shore so that we can have our own dock within a stone's throw of the laboratory. Furthermore, there is room enough on the lawn to spread nets to dry.

It is one of the unfortunate features of oceanography that much of it has to be carried out at sea, so the amount of work that can be done at any headquarters depends very much on what one has in the way of boats and so forth. Hence the fact that the Woods Hole Institution will be able to have unusually good marine equipment makes it rather unique at present among institutions of a similar sort. From the very first it has been acknowledged as a foremost principle in all discussions that whatever else the Institution might or might not do, it should devote a substantial part of its endowment to the construction and operation of a ship large enough and seaworthy enough to carry on work of various sorts anywhere on the high seas at any time.

Actually we have planned to devote nearly 30 per cent of our total expenditure for construction towards building the ship and about one-third of our operating endowment towards running it. This having been decided, the next question was what sort of a ship should one have. And this is a very important question because the type of ship, of the size that we could afford to run, would very largely influence the kinds of work that could conveniently be done.

Nowadays, when oceanographic investigations are carried out in connection with the Fisheries Research, most of the research-ships that have been built of late by European countries are of the trawler-type. For instance, the Dana, upon which Schmidt has just made his famous circumnavigation, is a typical Mersey trawler. And when any experiments are to be made with modern commercial fishing-gear, this is about the only type that will serve. But our requirements are different, for on the one hand we shall not experiment with commercial fishing-gear. We shall leave this to the Bureau of Fisheries. But, on the other hand, we do want to carry on chemical work, and work in experimental biology on board ship.

Now the chief requirements for these things on a vessel are (1) space and (2) steadiness. The only possible way to keep a small vessel really steady at sea is by the use of sails. All small ships driven by power alone, no matter how safe they are, tumble around so that it is very difficult to carry on delicate chemical work on board. Also there is another side to this, namely, that it would be silly to ignore--seasickness. A party of seasick scientists is not very helpful. Other advantages of having sail as well as power are that the cruising radius is limited only by the supply of food and water, that the cost of operation is much lower per day, and that with the smaller engine, there is much more living-space on board. This last consideration is decidedly important on a small ship, for on an auxiliary, one can have all the living-quarters below the main deck, so that the latter can be kept clear of deck-houses. The only real drawback to an auxiliary is that she is slow. But for many sorts of work, this is not a serious consideration.

After much discussion, we finally settled on what one may call a larger and more refined idea of the type of ship made famous by the Armauer Hansen. It is absolutely essential, when one is building a craft of this sort for oceanographic work, to have the hull of such a form and the rig of such a type that the vessel will hold position when hove-to on station, that is to say, she must not drift sideways too fast. Our long experience in the Gulf of Maine and the North Atlantic generally, with the old Grampus, had taught us that this is entirely feasible.

The development of these ideas is the Atlantis, recently built in Copenhagen and now nearly ready for sea. Atlantis is a steel ketch, with Diesel engine of 250 horsepower, 142 feet long overall, 29 feet broad, drawing 15 feet of water, and of 380 tons displacement. She is designed for a speed of about 8 knots under power and should give a good account of herself under sail with moderate and heavy winds.

It is not reasonable to expect people--and especially landsmen--to do good scientific work at sea if they are not happy, so especial attention has been given to the arranging of comfortable quarters. Living-accommodations include single and double cabins for a scientific staff of six, while six to eight students can be accommodated in a dormitory. There are two large laboratories, one on deck and one below, so that there is plenty of room of physical-chemical as well as biological work on board.

The heavy-duty electric winch with its 30,000 feet of dredging wire is located in the hold, but with the controls, of course, on deck. There is also a hydrographic winch for sounding, while sonic gear will be installed later. With this basic equip-

ment, the Atlantis can work down to any depth. One would take it for granted that there will be a full equipment of nets, thermometers, water-bottles, etc. I am so often asked about the size of the personnel that I might add that the crew will number about forteen.

According to the present plan, Atlantis should start west from Plymouth, England, about July 10, 1931, to spend about 50 days en route to Woods Hole, which allows the equivalent of about 30 days for work and 20 days for sailing. The scientific program is now pretty well developed for this first cruise, and includes both physical and biological work. The former will consist chiefly of running two profiles across the outer edge of the North Atlantic Drift, the first running from the Azores northward, the second running inshore toward southern Nova Scotia from a point some 600 miles in the offing. In the runs between these profiles, various stations are planned to fill in existing gaps.

I am very happy to announce that Dr. Johannes Schmidt has offered to run in June the same profile from the Azores which we intend to run in July, which should give very valuable data as to seasonal progressions. In return we are undertaking to make special tows in the places he thinks most productive of larval eels, in order to supply lacking data. C. O. Iselin, who is master of the Atlantis, will be in charge of the physical work.

We are now discussing the possibility of planning for this first cruise some chemical work, but are not yet ready to make any announcement. The biological program so far arranged for the cruise includes three items, first, the eel-investigation, second, a study of vertical distribution and migrations of the plankton in the Atlantic basin in relation to the penetration of light, which will be in charge of George Clarke. For the measurement of light we hope to use the apparatus that Russell and Atkins have developed at Plymouth, England. The third item will be towing for bathypelagic fishes with very large nets at depths greater than those usually studied, and at as high speeds as possible. I need hardly add that one thing we have in mind is the possibility of catching more of the big deep-water fishes than has previously been done.

As I have said, the laboratory will be open in June. We are building a 40-foot work-boat to use near shore so that we do not have to await the arrival of the Atlantis to get started at Woods Hole.

About a dozen people have so far been appointed to the staff and perhaps I need not name them here for they are all listed in the first annual announcement of the Institution which has just come from the printer. If any of you are sufficiently interested, you will also find there what we expect to do about research-assistants, about visiting investigators and about instruction; also a statement of the dozen or fifteen projects which are arranged for this summer.

This is perhaps enough to show that the affair is really under way and has gained momentum sufficient to give some assurance that it will continue to go ahead. And so we come to the most interesting question of all, which is, along what lines may we expect development to progress in the future, for we must not forget that all this physical plant is only a means to an end. What are we going to do with it? Now an oceanographic institution necessarily differs from any other marine laboratory in one respect, which is that people carrying on work there cannot act entirely independently, but must be directed to some extent. This applies not only to the staff but also to visiting investigators. The reason is obvious enough, as is the reason why no one institution can possibly take on all fields of sea-science at once--simply that there is a limit to the amounts and kinds of work that the ship can do simultaneously.

If the output of the Institution is to be really fertile, it is necessary to undertake some central program around which other things can be built. And so we have been giving much thought to this ever since the existence of the Institution was assured. Of course, the whole thing is in its initial stage, and we must feel our way. But we have reached the point where some announcement may be made. There is, to begin with, a crying need for cooperation between the two sides of the Atlantic in the study of the circulatory problems in the North Atlantic.

I have just had the very good fortune to meet many of the more active oceanographers in Europe at the recent meeting of the International Council for the Exploration of the Sea, and to talk over this question. We plan two initial steps in this field after the Atlantis reaches Woods Hole. One will consist of periodic surveys of an oceanic quadrangle off this coast to be repeated four times a year for several years, with lines running out several hundred miles, in order to keep track of the general state of the water and especially of the fluctuation in location of the demarcation between the inshore- and offshore-waters. A study of thermal distribution and variations in this side of the Atlantic based on thermograph-readings which is to be started at Woods Hole this summer, under the general supervision of Professor Brooks, may be looked on as a part of this general problem.

The second task is an intensive examination of the waters to the south of Greenland, especially in winter, in order to throw light on the manufacture of bottom-water for the North Atlantic. It is not yet certain how soon we can undertake this, but it is one of the things that faces us in the future. And third, the matter of interaction between sea-surface and overlying air is now much to the fore. As our initial contributions here, we hope to start studies, both out at sea and inshore, of thermal interchange and of the stress exerted by the wind as a propulsive force; these are to be in charge of Professor C. G. Rossby.

For the rest our aim is as much as possible to support lines of work that seem important in the general synthesis of science, but which are neglected elsewhere, rather than to make it a prime effort to do more of what other people are doing. A crying case of this is afforded by the whole subject of bacteriology in the sea, from the standpoint of the overturn of matter there. The Institution has already arranged to start work in this subject during the coming summer, and accordingly, as progress is made, more and more of our time and effort will be devoted to it.

We also believe that by the appointment of Dr. Alfred Redfield to the staff--which I am happy to announce--experimental studies into the biology of marine animals from the point of view of their physical adaptations to their surroundings will be raised to a new plane. We are also planning during this first summer to start certain investigations on the actual modes and efficiency of the transport of sediments over the sea-bottom under different conditions of currents, waves, etc. And we are now planning for various studies on plankton, and on the characteristics of the inshore-waters south of Cape Cod.

It may also be of general interest that Mr. Mossby, the senior physical oceanographer of the Coast Guard who has recently been appointed to the Ice Patrol, will probably make his headquarters at the Woods Hole Laboratory after he returns from the Grand Banks, and that the Institution has appointed Sir Hubert Wilkins an honorary member of the staff and made some contribution to his forthcoming expedition, feeling confident that if all goes well, we may expect Sir Hubert and Dr. Sverdrup to bring back data of great value as to the oceanography of the North Polar Basin.

So much talk of projects to be started, with so little of things actually done, may savor too much of prophecy, but I know no better way of setting forth our present prospects. Next year let us hope we can come before the Union with some account of scientific advances actually made.

Woods Hole Oceanographic Institution,
Woods Hole, Massachusetts

OCEANOGRAPHIC WORK OF THE UNITED STATES HYDROGRAPHIC OFFICE

W. R. Gherardi

The use of the sea, from early times, as the great highway of transportation and communication has made apparent to the United States the advantage of supplying its vessels with information regarding those waters through which their voyages are conducted. These advantages are made possible in practice by a national institution, the Hydrographic Office of the Navy, established in the Navy Department and serving both the Navy and the Merchant Marine. This institution produces and issues in successive

editions more than three thousand different publications relating to the oceans, including charts ranging in continuous succession throughout the entire oceanic expanse.

Until recent times the charts were encumbered with symbols to represent the thousands of reports of doubtful dangers to navigation that had come down from former generations of navigators. To furnish evidence, by measuring the depth of the ocean, that would verify or disprove these reports, sometimes doubtless based upon deceptive appearance of the surface of the sea, became a recognized obligation of the United States Navy. This resulted in this Service becoming a pioneer in furnishing authentic measurements of the depths of the ocean.

The charts of the Hydrographic Office have thus become, by natural development, the repository of the accumulated information with respect to the conformation and topography of the bottom of the ocean, and in them may be found the facts of observation that lend themselves to the delineation of the isobathic contours.

There is no doubt that, from the standpoint of geophysics, the mapping of the features of the floor of the ocean is of an order of importance scarcely secondary to the importance of portraying the topography of the continents. Accordingly, I desire to bring to the special notice of this Section of the American Geophysical Union the accelerating rate of the stream of measurements of deep-sea soundings from vessels of the Navy in the course of ocean-voyages. This work is now advancing the once distant prospect of mapping the configuration of the oceanic basins to a near stage of feasibility. The details of the accessions thus acquired during the last year are given in a report of the Committee on Submarine Configuration and Oceanic Circulation to the meeting, now taking place, of the Division of Geology and Geography of the National Research Council. In this report there will also be found an account of the marine hydrographic surveys by vessels of the Navy, assisted by naval aircraft, in Cuba, Venezuela, and the Pacific approaches to the Panama Canal.

Since this report was submitted the U.S.S. Fulton--one of the United States Navy surveying vessels assigned to the Hydrographic Office--has investigated Guardian Bank, reported to be located about 100 miles off the west coast of Costa Rica. Soundings obtained during the last few years by vessels in that area have shown a great variation in depth and position. The Fulton, after taking 9,000 soundings over an area of 900 square miles, was unable to obtain a less depth than 1,700 fathoms. The primary work upon which the U.S.S. Fulton is engaged is the hydrographic survey of the Gulf of Panama and it was necessary to return the vessel to this work, but it is hoped to be able to spare her services for sufficient time during the next survey-season to make further investigation near this Guardian Bank.

The U.S.S. Nokomis has completed her survey-season's work on the northeast coast of Cuba and it is estimated that another survey-season will complete the entire survey of the Island of Cuba. The U.S.S. Hannibal has completed her season's work in the Gulf of Paria, Venezuela. That vessel will return to the same area next year and upon completion will proceed to the eastern shores of Central America with a view to charting correctly the approaches to the proposed Nicaraguan Canal.

An analysis of the reports of the set and drift of the surface-waters of the North Pacific Ocean has yielded results, of the same nature as those heretofore deduced in relation to the Atlantic Ocean, setting forth the distribution in direction, strength, and frequency of the currents in successive tracts. These tracts are bounded by integer-degree meridians of longitude five degrees apart and integer-degree parallels of latitude five degrees apart, extending in succession from North America to Asia. The summaries, which have been made month by month for March, April, May, June, July, and August, have appeared in relation to those parts of the ocean west of the 180th degree meridian from Greenwich, in the form of current-roses, printed with the issues for April 1931 and July 1930 of the Pilot Chart of the North Pacific Ocean, and likewise, in earlier issues, in relation to the eastern part of that Ocean.

From the accumulation of reports of mariners during the years from 1915 to 1924, now in course of reduction, there is the prospect of the early completion for publication of the monthly average of temperature of the surface-waters of the North Pacific Ocean in successive tracts bounded at interval-degree meridians of longitude and parallels of latitude.

Under the auspices of the Hydrographic Office, a self-registering tide-gage has been maintained in continuous operation, under exceptionally competent management, at Papeari, Tahiti, in the Tuamotu Archipelago, since December 1923. Besides the materials for tidal investigation in the Pacific Ocean thus accumulating and already reflected in the United States Tide Tables published by the Coast and Geodetic Survey, the expectation of continuance in the production from this gage of records of the fluctuations of the level of the oceanic waters holds out the prospect of supplying information regarding seismological events.

U. S. Hydrographic Office,
Washington, D. C.

OCEANOGRAPHIC WORK AT THE SCRIPPS INSTITUTION OF OCEANOGRAPHY, UNIVERSITY OF CALIFORNIA, DURING THE PAST YEAR

T. Wayland Vaughan

In these notes on oceanographic investigations at the Scripps Institution of Oceanography, only those in the fields of physical oceanography, marine meteorology, the chemistry of sea-water and marine bottom-deposits will be mentioned.

The Scripps Institution, as aids in its investigations in physical oceanography and related subjects, has continued to receive water-samples and records of sea-surface temperatures and meteorological data, partly through the cooperation of the Bureau of Lighthouses, from the pier of the Scripps Institution at La Jolla and the pier at Balboa, from Pacific Grove, Hueneme, Farallon Islands, Blunts Reefs Light-Ship, and lighthouse-tenders Lupine and Sequoia. Information has also been received from the United States Naval transports, the vessels Guide and Discoverer of the United States Coast and Geodetic Survey, from the Escuela Naval at Callao, Peru, and the Grace Line ships between Valparaiso and Central American ports. The Institution has a water-thermograph installed on its own pier, on the Los Angeles Steamship Company's S.S. Calawaii, which makes fortnightly trips from Los Angeles to Hawaii, and on the United States lighthouse-tender Lupine. During the year 3,123 salinity-determinations were made at the Institution and 10,453 records of temperature, 9,766 records of wind, and 2,860 records of air-temperature were received.

Thermographs recording condenser-intake temperatures have been installed on four steamers of the Canadian Pacific Company since 1923, and the records have been reported regularly to Director John Patterson of the Meteorological Service, Toronto, Canada, but no provision had been made to work up the material collected since September 1928. During the past year by means of a cooperative arrangement with the Scripps Institution the work has been completed to date. Copies of the tabulations for the period 1923 to 1930 have now been made available.

Arrangements were made with the United States Weather Bureau for having original records of sea-surface temperatures, winds, and air-temperatures copied on special forms for use at the Scripps Institution. This work was done by Miss Edith M. Fitton and Miss Dorothy E. Chapin, assistants of Charles F. Brooks in the Department of Meteorology at Clark University.

The tabulation of data for an area of about fifty one-degree quadrangles in the San Francisco region of the Pacific collected since 1898 has been completed. This material will be used in connection with other surface-data in the eastern North Pacific for investigating surface-drift and the problem of seasonal long-range forecasting.

Serial observations at station 1, ten miles west of the Scripps Institution's pier, have been summarized, and progress has been made with the observations at station 2, five miles offshore. Weekly and monthly averages of all shore-station data have been worked out to date, and mimeographed copies are available for distribution. Blue-prints of seasonal curves plotted from weekly averages are also available for distribution. Tabulation of surface-observations at sea according to 30-minute quadrangles and weeks or months has continued as usual. Entering the data collected during the past seven years on especially prepared charts was commenced in April. It is planned to carry on an investigation of surface-drift, using this material as a basis

During the year Dr. McEwen published the following papers:

A survey of some of the methods used in modern dynamical oceanography. Contrib. Marine Biol., Stanford Univ. Press, 57-68, 1930.
Hydrographic sections and calculated currents in the Gulf of Alaska, 1928-1929 (with Thos. G. Thompson and Richard Van Cleve). Rep. Internat. Fish. Comm., No. 4, 36 pp., 1930.
Review of "The Sea," by H. A. Marmer. Geog. Rev., v. 20, 707-708, 1930.
Seasonal rainfall forecasting based on Pacific Ocean temperatures. Calif. Citrograph, v. 16, 3, 22, 23, 26, 1930.
Our rainfall: How is it formed and what becomes of it? Sci. Mon., v. 31, 385-400, 1930.
Indicated seasonal precipitation for 1930-31 in selected regions of California (with A. F. Gorton). Bull. Amer. Met. Soc., v. 11, 169-171, 1930.
Results of evaporation studies conducted at the Scripps Institution of Oceanography and the California Institute of Technology. Scripps Inst. Oceanogr. Bull., Tech. Ser., v. 2, 401-415, 1930.
A limnological study of lakes and reservoirs of San Diego County. Published in abstract in the Proceedings of the Water Supply and Purification Section, School of Citizenship and Public Administration, Univ. S. Calif., Los Angeles.
A summary of basic principles underlying modern methods of dynamical oceanography. In volume on Oceanography of series The Physics of the Earth, Bull. Nation. Res. Council.

Investigations of problems of evaporation were continued during the summer at the Scripps Institution by N. W. Cummings and Burt Richardson. The following papers were published:

N. W. Cummings, Alignment diagram for "R" of the energy evaporation-equation. Mon. Weath. Rev., v. 58, 142-144, 1930.
N. W. Cummings, Certain limitations on the possible value of the ratio of heat losses by convection and by evaporation at a water-surface. Mon. Weath. Rev., v. 58, 144-146, 1930.
Burt Richardson, Evaporation as a function of insolation. Proc. Amer. Soc. Civ. Eng., v. 56, 945-980, 1930.

Cummings prepared a report outlining a new method of determining transpiration and he calibrated a monel metal "sinker" 25 cc volume in order to check salinity-determinations made at Scripps Institution.

Richardson made a number of test-measurements of the intensity of solar radiation at various depths in the sea and prepared for publication a report entitled "The photoelectric measurements of the penetration in sea-water of light (wave-length 2,900 to 4,800 Ångstrom units)."

A. F. Gorton continued his studies of the problem of long-range forecasting of seasonal rainfall on the Pacific Coast of North America. In addition, he investigated the problem of forecasting air-temperatures in the central region of Southern California.

Records of the Institution's apparatus for recording the intensity of solar radiation (pyranometer) were analyzed and found to throw much light on the optical transmission- and reflection-characteristics of fog, haze, and clouds.

Gorton applied the method of strato-analysis to records of precipitation, stream-flow, and lake-levels in Brazil, Australia, and South Africa, as well as regions of the north temperate zone, and discovered the same fundamental periodicities in the southern hemisphere as in the northern. He published the following papers.

Note on progress of seasonal weather-forecasting in California (with Agnes Partridge). Bull. Amer. Met. Soc., v. 11, 149-150, 1930.
Long-range weather-forecasting. Electrical West, v. 65, 112-115, 1930.
Indicated seasonal precipitation for 1930-31 in selected regions of California (with G. F. McEwen). Bull. Amer. Met. Soc., 1930.
Forecasting seasonal precipitation. J. Amer. Inst. Elec. Eng., v. 49, 996-1001, 1930.

Pyranometer-records assist in distinguishing between haze and clouds (with S. W. Chambers). Month. Weath. Rev. (in press).

Long-range weather-forecasting in California. Los Angeles Times, Sunday Magazine Section (in press).

La Jolla ocean-temperatures during the upwelling period and their values as indices of atmospheric temperature and domestic gas-consumption during the winter season. Bull. Amer. Met. Soc. (in press).

Last year's report contained a rather complete outline of the chemical investigations in progress at the Scripps Institution and for that reason only those studies that have received particular attention during the current year are mentioned in the present report.

Further work on the determination of calcium in sea-water, carried out by Dr. P. L. Kirk of the Division of Biochemistry, University of California Medical School, indicates that a micro-method, which is rapid enough for routine work, will give results of the same order of accuracy as those obtained by standard methods. The studies of the interrelation between carbon dioxide, hydrogen-ion concentration, and the total base in sea-water are also being continued. Attempts have been made to find a suitable method for the determination of boron in sea-water and some progress has been made. In order to increase our knowledge of the inorganic nitrogen compounds in the sea, determinations of the nitrite-content of the water in this locality have been carried out at regular intervals during the past year.

During 1930 the following papers have been published:

E. G. Moberg and H. W. Graham, The distribution of oxygen in the Pacific as an index of the circulation of water. Dept. Terr. Mag., Carnegie Inst., Washington, Rep. and Comm. Stockholm Assembly, Internat. Geod. Geophys. Union, Sec. Oceanogr., 95-97, June 30, 1930.

E. G. Moberg, H. R. Seiwell, H. W. Graham, and J. H. Paul, The phosphate-content of the surface water in the Pacific as related to the circulation. Ibidem, 98-100, June 30, 1930.

E. G. Moberg, Distribution of oxygen in the Pacific. Contrib. Marine Biol., Stanford Univ. Press, 69-78, Sept. 1, 1930.

E. G. Moberg, Circulation of the waters of the Pacific Ocean as indicated by their physical and chemical properties. (Nation. Acad. Sci.) Science, v. 72, 374, 1930.

The investigations of marine bottom-deposits conducted at the Institution during the past year included the completion of a paper entitled Descriptions of some deep-sea bottom-samples from the western North Atlantic and the Caribbean Sea by Eidon M. Thorp, which is now in proof as a bulletin of the Scripps Institution, Technical Series, volume 3, No. 1, University of California Press. During the year Mr. Thorp has very nearly completed the preliminary description of the shoal-water calcium-carbonate sediments collected by T. W. Vaughan in the Bahamian and Floridian regions between 1908 and 1915. This study when completed will give information on a variety of shoal-water calcium-carbonate sediments in the region from which the specimens were collected, and a basis for comparison of the different kinds of sediments over the range of conditions from the beaches and very shallow water to abyssal depths in the sea.

The Scripps Institution received a complete set of the deep-sea samples collected by the Carnegie on its last cruise. The mechanical analyses of all samples, of which the quantity of material was sufficient, have been nearly completed and arrangements have been made for the detailed description of the different samples.

Scripps Institution of Oceanography,
La Jolla, California

OCEANOGRAPHIC WORK OF THE UNITED STATES COAST AND GEODETIC SURVEY DURING THE PAST YEAR

E. H. Pagenhart

This report covers briefly the hydrographic surveys, tide-and-current surveys, and the office reviews which follow the field-work; for they are the oceanographic activities of the Bureau. They are of course correlated with the other activities such as triangulation, leveling, magnetics, gravity, and seismology, all of which are either necessary as basic information or are valuable in interpreting the results of the oceanographic work.

Hydrography--The hydrographic work is pretty widely scattered (see Fig. 1). In the Philippine Islands three vessels, the Pathfinder, Fathomer, and Marinduque are continually working and the original surveys begun in 1899 are nearing completion. The Pioneer is on Hawaiian duty working among the islands during the winter and in summer out along the chain of islets and rocks which are the tips of the submerged mountain range that extends for over a thousand miles westward to Midway along the steamer lane to Japan. The Guide was on the Washington coast completing the survey from the shore to beyond the 1,000-fathom curve, that will give the navigator for the first time complete and recent information all along the coast from Mexico to the Canadian boundary. Three ships were in Alaska, the Explorer in Behm Canal, the Discoverer off Prince William Sound, and the Surveyor on a progressive survey of Kodiak Island.

On the Atlantic three ships, the Lydonia, Oceanographer, and Natoma and several launch-parties have been at work. Surveys have been made along the east Florida coast; in the Hudson just above New York; a wire-drag survey in Long Island Sound; and an important survey of the eastern end of Georges Bank well off the New England coast. These projects summed up give 130,000 square miles of hydrography, an area one-half the size of Texas, which could not have been accomplished by pre-war methods.

The new methods put in practice during the past decade have now settled down to routine with resulting larger output and greater precision.

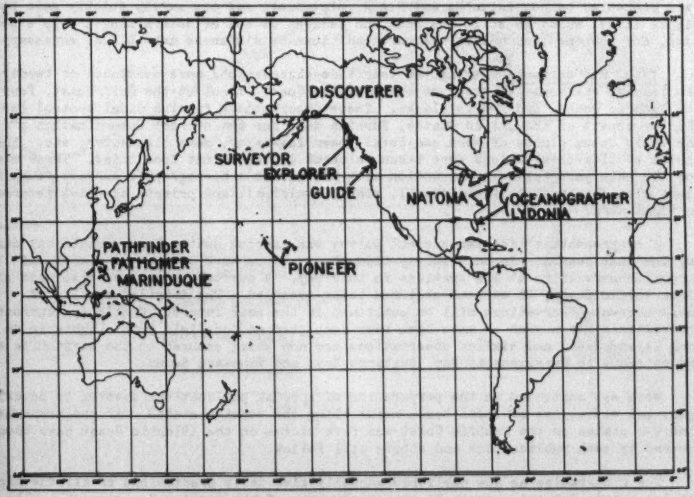

Fig. 1--Location of survey-vessels, United States Coast and Geodetic Survey, 1930

Echo-sounding or depth-determination by measuring the time for sound to travel from the surface to the bottom and back to the surface permits the survey-ship to obtain almost a continuous bottom profile at full speed.

Radio acoustic sound-ranging, the method of position-determination by distance from two known points, measured by the time required for sound to travel from ship to the known points, where receiving instruments automatically radio the signal to the ship, enables the surveying-vessel to fix its position on a sounding-line far beyond all landmarks, or in darkness, or in fog.

Constant use of these methods has suggested and will continue to suggest simpler instruments, greater precision, and better ways of getting desired results, so there is still opportunity for future developments.

During the year the survey of Georges Bank was undertaken. This bank extending for 160 miles eastward from Cape Cod and Nantucket Shoal is a famous fishing-ground with heavy coastwise traffic while the Atlantic steamer-tracks from Boston and New York pass close on either side. Strong currents and fog are the rule which is frequently broken by storm. Despite these difficulties two ships engaged on this project, the Lydonia and Oceanographer, were able to cover 7,000 square miles of area on the eastern end of the bank. As it was known that the work would extend beyond one season, several permanent buoys were planted and located to coordinate the different seasons work, as well as many temporary survey-buoys. One of the ships was stationed at the hydrophone-buoy while the other ran the sounding-lines by a combination of dead-reckoning and the single R.A.R. distance. Every possible precaution was taken to improve the dead-reckoning; one of the new devices which was helpful was an electric log set into the bottom of the ship with the indicator on the bridge. This was especially valuable when maneuvering required the taffrail-logs to be hauled in. As the past season demonstrated the practicability of R.A.R. in this locality a second hydrophone-ship and another survey-ship will be provided for the coming season. Another example of offshore development but under favorable conditions is that of Raita Bank, 20 miles long with depths of 20 fathoms, located out in the middle of the Pacific Ocean 60 miles from the nearest bare reef. Buoys were planted on the bank and positions determined by a number of astronomical sights and as a check the buoys were connected by sun-azimuths and R.A.R. distances, and the survey quickly made by visual fixes, which is still the best and easiest method of determining a ship's position, and the one used unless weather-conditions or distances make R.A.R. necessary.

Tides and currents--During the year tide-observations were continued at twenty-two primary stations--thirteen on the Atlantic Coast, three on the Gulf Coast, four on the Pacific Coast, and two in Alaska. These observations furnish tidal control for all the coasts of the United States, furnish data for the correct determination of the basic datum planes of mean sea-level, mean low-water, mean high-water, etc. Short series of tide-observations were taken in about 100 different localities. These were for the main part taken in connection with the Bureau's hydrographic surveys, but include also observations from federal, state, municipal, and private agencies interested in tidal work.

A comprehensive tide-and-current survey was carried out in Narragansett Bay during the past season. In this survey tide-observations were made at 18 places and current-observations at 125 stations in this bay. A current-survey was also made of Block Island Sound, 25 current-stations being occupied. The detailed results of these current-observations will be published in the near future. Continuous current-observations for a year or more have been completed at Cornfield Point Lightship on Long Island Sound and similar observations are now being secured on the lightships at the entrance to Narragansett Bay, Buzzards Bay, and Vineyard Sound.

Work was continued on the preparation of special publications devoted to descriptions and elevations of tidal bench-marks along the coastal states. At the present time two states on the Pacific Coast and five states on the Atlantic Coast have been covered by such publications and others will follow.

The tide-tables as now published annually give daily predictions of all the high- and low-waters for the year at 94 principal ports of the world. The current-tables give predictions for thirteen principal stations on the Atlantic Coast and eleven on

the Pacific Coast. They also give data which will permit predictions to be made at 1,200 other places by reference to the principal current-stations. Pocket-size tables including predictions for both tides and currents are now issued annually for four important waterways, namely, Massachusetts Bay, New York Harbor, San Francisco Bay, and Puget Sound. Tidal current-charts are now being issued for Boston Harbor, New York Harbor, and San Francisco Bay with such a chart for Chesapeake Bay in process of construction.

For the coming year it is planned to continue tide-observations at 22 primary tide-stations and to make a comprehensive tide-and-current survey of Buzzards Bay.

Field-records and charts--In the Washington office where all of the field-sheets and records are sent, it is possible to make valuable studies and reach conclusions based upon a wide variety of conditions which could not be had elsewhere. The office study of all available R.A.R. records disclosed the fact that the path of the sound-wave from ship to shore which actuates the hydrophone may for practical purposes be assumed to be along the bottom where it is not too far below the surface, and where the temperature is coldest rather than through the warmer, speedier medium of surface-water.

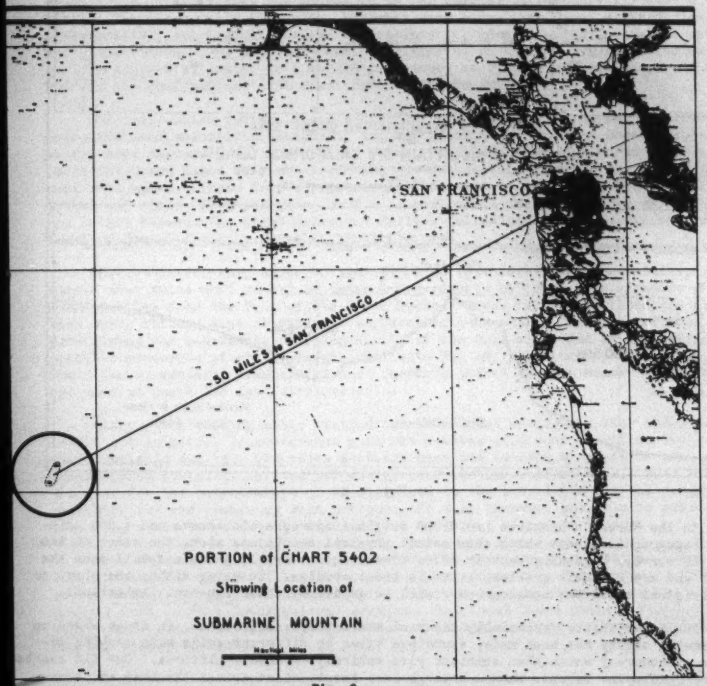

Fig. 2

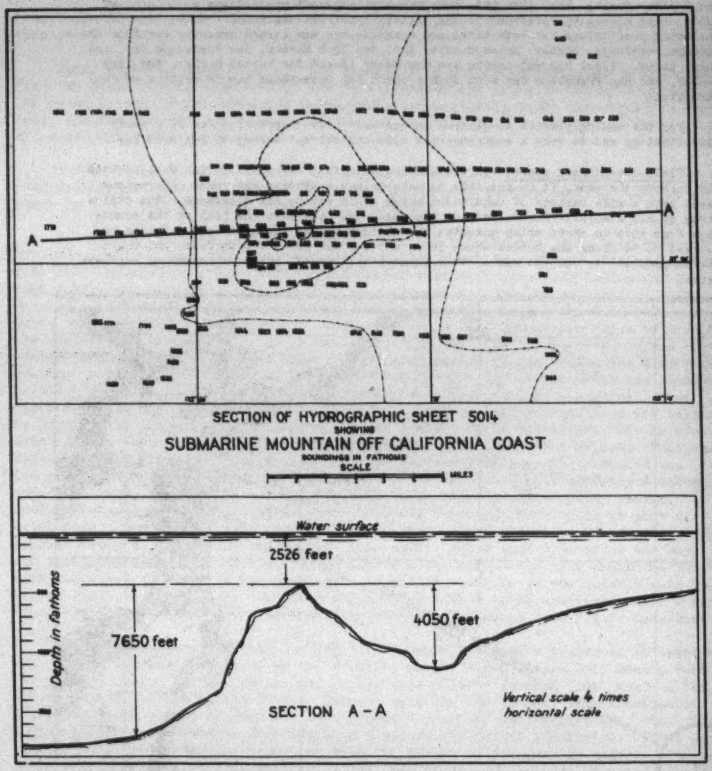

Fig. 3

In the Bureau's archives are 5,000 original hydrographic sheets and 4,500 original topographic sheets which show actual physical conditions along the coast at the time of survey, beginning back in 1834. These sheets are in greater detail than the chart and are of their greatest value in local studies. In using either the chart or the original sheet the oceanographer will be guided by their inherent limitations.

Published charts, especially those of small scale, often show, in areas where no systematic survey has been made, soundings taken by different ships with varying degrees of accuracy which when combined give entirely erroneous pictures. Our old charts of the Philippine Islands showed a large lump twenty miles across the base and some 13,000 feet high, in the middle of the Sulu Sea based upon what proved to be an erroneous sounding of 95 fathoms and two badly misplaced soundings of 560 fathoms and 470 fathoms. This remained for years on the chart with its tip just below the surface until the survey-ship came along and removed it entirely.

I should like in closing to bring to your notice a recently discovered but safely submerged peak rising 4,000 feet above the bottom, 50 miles southwest from San Francisc

on the great-circle course to Honolulu (see Figs. 2 and 3). This might quite easily have been missed in a regular survey before the days of the fathometer, for the reason that in the older method it was necessary, if one wanted to make any progress, to space the deep-sea soundings on the line about the same distance apart as the distance between lines.

U. S. Coast and Geodetic Survey,
Washington, D. C.

OCEANOGRAPHIC WORK CARRIED ON BY THE UNITED STATES COAST GUARD DURING THE ICE-PATROL SEASON OF 1930 AND THE PLANS FOR OCEANOGRAPHIC WORK TO BE CARRIED ON DURING THE ICE-SEASON OF 1931

N. G. Ricketts

Icebergs were reported off the Grand Banks of Newfoundland very early in 1930, causing the International Ice Patrol to be inaugurated on February 11, over a month earlier than is usually the case. Somewhat more bergs than usual drifted south of the 48th parallel, but they all melted before June 12, when the 1930 Ice Patrol Service was discontinued. The unusually early clearing up of the iceberg-situation was due, in a large part at least, to a marked deficiency of field-ice about the Grand Banks and off the Newfoundland east coast earlier in the spring.

The Coast Guard cutters Modoc and Mojave while on Ice Patrol duty in 1930 had on board the same scientific equipment, and continued doing the same oceanographic work as has been customary for a number of years. In 1930, several hundred sonic soundings about the Grand Banks were obtained with the fathometers when the ships' positions were well known. These were corrected and forwarded to the United States Hydrographic Office and others at Washington, D. C. No noticeable change of depth was detected in the waters between the Grand Banks and Halifax following the earthquake that occurred south of Newfoundland in November 1929.

The Ice Patrol ship observed some 3,000 surface sea-water temperatures, and received over twice that number of temperature-reports by radio from a radius of four hundred miles from the Tail of the Grand Banks. These values permitted the construction every fifteen days of detailed surface isotherm-charts that were of much value in determining the constantly shifting limits of the cold wall, and in predicting the probable movements of the icebergs. Bulletin No. 18, published by the United States Coast Guard, contains examples of such isotherm-charts and the manner in which they are used on board the Ice Patrol vessels.

Sixty-seven oceanographic stations were occupied during the 1930 ice-season, and worked out on patrol in accordance with the methods laid down in United States Coast Guard Bulletin No. 14. The above stations were not located in place or time at very advantageous positions for the purpose of constructing current-maps. This was due to the need for the patrol-ships to remain close to the ice limits for the purpose of searching for and remaining with the ice. It was, however, possible to make some interesting sections across the cold wall at different times and places.

More valuable results are expected from the oceanographic stations taken during 1931, because of the detailing to the Ice Patrol force of a third vessel, the 125-foot cutter General Greene, which vessel will carry on the ice observation-duty and oceanographic work of this international service. The Coast Guard cutters Pontchartrain and Mojave have been detailed to perform the normal ice-scouting and ice-patrol duties during the season of 1931.

In order to perform the duty of oceanographic vessel which involves the procurement of scientific data necessary for the frequent construction of current-charts of such areas in the Grand Banks regions as may become critical with regard to ice from time to time, and for a study and observation of ice-conditions, the General Greene has been supplied with a fathometer and all the scientific apparatus usually carried to sea by the two large patrol-vessels, and will be manned by especially trained personnel. Olav Mosby, an expert oceanographer, a native of Norway, and educated at the University of Oslo, has been appointed Senior Physical Oceanographer. He is attached

to the General Greene and will supervise the making of the necessary oceanographic surveys and charts in an effort to predict imminent ice-movements. To this end he will procure the proper data of salinity and temperature at various stations, the precise locations of which are to be determined in accordance with a general plan already developed in consultations with Dr. Henry B. Bigelow, Professor of Zoology at Harvard University, and Lieutenant-Commander Edward H. Smith, United States Coast Guard, both of whom are prominent in the scientific field of oceanography.

The scientific program of the General Greene after the inauguration of the Ice Patrol will require the vessel to occupy numerous stations on the Grand Banks and vicinity in order to secure temperature- and salinity-data from which to construct current-charts, it being understood that the two principal factors utilized in the determination of currents for ice-predictions are temperature and salinity.

The General Greene sailed from Boston, Massachusetts, on March 18 to scout for icebergs on the Grand Banks prior to the inauguration of the International Ice Patrol. She has been directed to cruise to the northward along the eastern shores of Newfoundland and locate the southernmost bergs, determine their rate of drift, and when they will probably become a menace to shipping-lanes. Having located the southernmost bergs she will advise Coast Guard Headquarters, Washington, D. C., of the probable date that the usual continuous Ice Patrol service will be needed. In the prosecution of her work the General Greene will base on St. Johns, Newfoundland, if that port be open, otherwise on Halifax, Nova Scotia. It is expected that she will return to the United States about July 1931. To date (April 3) the radio reports from the General Greene indicate the prevalence of extraordinary ice-conditions north of the Grand Banks. She has as yet found no ice south of the 50th parallel, a condition practically without precedent for this time of the year, and indicative of a very light ice-year.

U. S. Coast Guard,
Washington, D. C.

PROGRESS-REPORT ON COMPILATION OF OCEANOGRAPHIC RESULTS, CARNEGIE CRUISE, 1928-1929

J. A. Fleming

Rapid progress since the reports (Pub. Nation. Res. Council, Trans. Amer. Geophys. Union, 10th and 11th Annual Meetings, 137-140, 200-206, 251-274, 299-300, June 1930) made at the eleventh annual meeting of the Union has been made by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington in the reductions and compilations of the oceanographic data obtained on the Carnegie. There has also been prepared by J. H. Paul, surgeon and observer on the Carnegie, a narrative account entitled "The last cruise of the Carnegie," which it is expected may soon be published and which, besides giving a narrative of the cruise, tells in somewhat popular style of the purposes of the oceanographic work and of the instruments necessary for that work.

It was possible for the Department to prepare on behalf of the Institution reports and communications dealing with the oceanographic work done on the Carnegie for presentation at the Stockholm Assembly before the Section of Oceanography of the International Union of Geodesy and Geophysics in August 1930. References to these communications and to other papers published which bear on the oceanographic work done are listed at the end of this report.

Excellent progress has been made on the compilation of the resulting data and the preparation of manuscript for publication later by the Carnegie Institution of Washington. These compilations and the discussions under the general direction of the writer have been done by H. U. Sverdrup, F. M. Soule, O. W. Torreson, C. C. Ennis, H. W. Graham, J. H. Paul, S. E. Forbush, Miss K. B. Clarke, Miss H. V. Miller, and S. L. Seaton of the Department staff, while Dr. E. G. Moberg and Dr. G. F. McEwen of the Scripps Institution of Oceanography also assisted during several months' stay at the Department. Summaries of the work done since the last report are given below.

Naturally, the loss of the Carnegie and the infeasibility of the provision of funds by the Carnegie Institution to build another non-magnetic ship has raised important questions on ways and means of obtaining future magnetic and electric observations at sea. A committee of the Department of Terrestrial Magnetism, including members of the staff who have taken outstanding part in the successful development of the Department's work over the oceans, made a report after considering ways and means that might be helpful in the development of oceanographic research with occasional magnetic and electric observations. Among the committee s recommendations of interest to the Section of Oceanography are the following: (1) Preparations by the Department to reproduce the magnetic and atmospheric-electric instruments for use at sea at the earliest possible moment--the design and construction of these instruments have already been begun; (2) prompt publication of the results of Cruise VII of the Carnegie, with special reports for the use of future expeditions--as indicated above, the manuscripts for such publication are already well under way; (3) the immediate preparation and distribution of various memoranda regarding experience acquired on the Galilee and on the Carnegie, with suggestions for improvement of methods, instruments, conditions, etc.--these have been prepared and distributed; (4) cooperation with proposed oceanographic expeditions to secure observations in magnetism, atmospheric electricity, or other physical phases of oceanography when the construction of the ship is found suitable for such work--steps in this direction have already been taken with the Woods Hole Oceanographic Institution, Scripps Institution of Oceanography, and the Oceanographic Laboratory of the University of Washington; and (5) the advocation of an endowment sufficient not only to purchase but to keep in practically continuous operation a vessel suitable for every phase of scientific research at sea. Copies of eight appendices accompanying the report of this special committee have already been distributed to organizations and individuals interested in forwarding the oceanographic investigations, as also to the International Hydrographic Bureau.

Physical oceanography

Temperatures and salinities observed at the 162 oceanographic stations in the Atlantic and the Pacific oceans have been finally corrected and vertical-distribution curves have been prepared for each station (for specimen, see Fig. 1). These curves have been scaled for even values of depth and for even values of temperature and salinity. Density-values have been computed from salinities and temperatures. Sixteen vertical sections have been prepared of each of these (salinity, temperature, and density--for specimen of temperature-section, see Fig. 2). Horizontal sections have been prepared for the Pacific for temperature and salinity at depths of 700, 1,500, and 3,000 meters, and those for 0, 100, 200, 300, 400, 500, 1,000, 2,000, and 2,500 meters are nearly completed. From the scaled values of temperature and salinity, dynamic depths of isobaric surfaces have been computed and from these computations charts showing the topography relative to the 2,000-decibar surface (for specimen, see Fig. 3) have been prepared for the 100-decibar surface in the Atlantic and for the 0-, 50-, 100-, 200-, 300-, 400-, 500-, 700-, 1,000-, and 1,500-decibar surfaces in the Pacific. Horizontal sections of density for the Pacific are in progress for the depths 0, 100, 200, 300, 400, 500, 700, 1,000, 1,500, 2,000, 2,500, and 3,000 meters. The final graphs showing temperature-salinity relations at different depths observed at each station are in the course of preparation for publication. Detailed tabulations of the observed data as finally revised and of interpolated values at standard depths for all of the physical elements observed have been prepared for final publication as shown in Figure 4.

The 1,499 sonic-depth determinations have all been finally corrected. The resulting values are excellently controlled by the depths frequently simultaneously determined by wire and by pressure-thermometers.

Sounding-velocities have been computed for each of the 162 oceanographic stations and 16 vertical sections have been prepared (for specimen, see Fig. 5). A horizontal section has been prepared for the Pacific for the 4,000-meter level. Boundaries between the areas of equal sounding-velocity as given by the British Admiralty Publication H.D. 282 have been investigated at the points of crossing of the path of the Carnegie and a chart has been prepared showing the locations of the boundaries at these crossings.

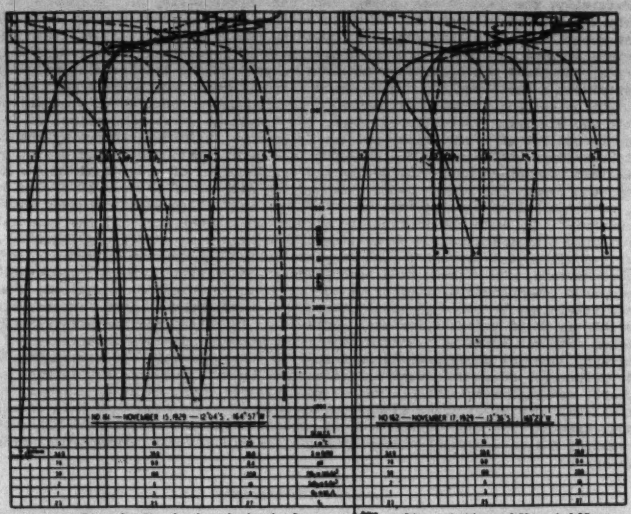

Fig. 1--Physical and chemical results, stations 161 and 162

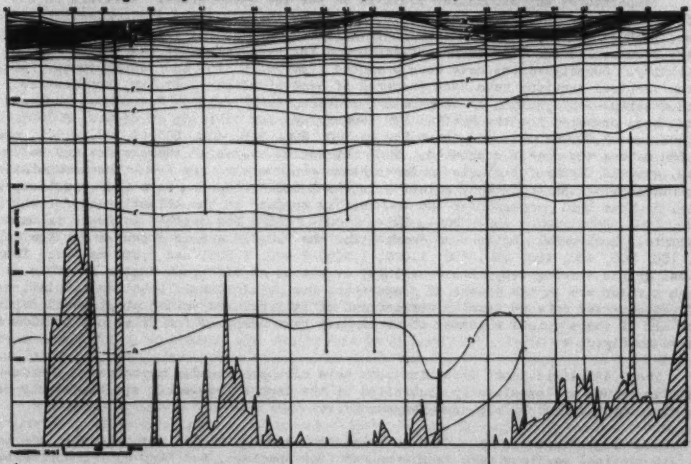

Fig. 2--Water-temperature distribution, stations 130-134 and 148-162

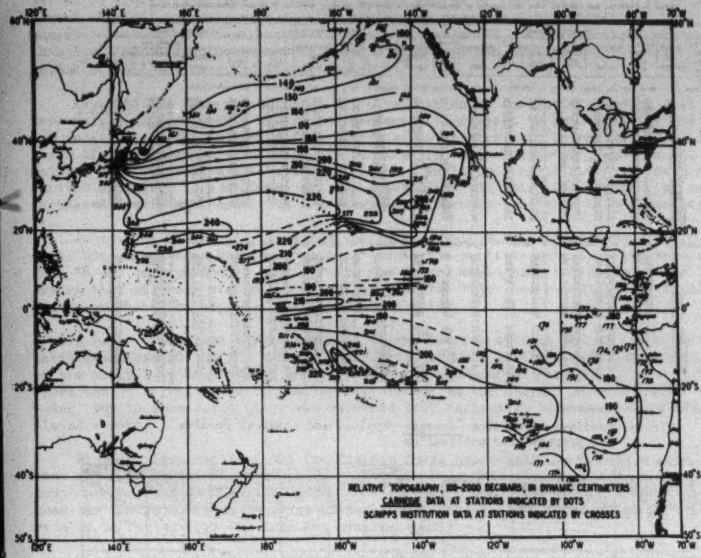
RELATIVE TOPOGRAPHY, 100-2000 DECIBARS, IN DYNAMIC CENTIMETERS
CARNEGIE DATA AT STATIONS INDICATED BY DOTS
SCRIPPS INSTITUTION DATA AT STATIONS INDICATED BY CROSSES

Fig. 3--Chart of relative topography, 100-2,000 decibars

Manuscripts have been prepared describing instruments, methods, and reductions involved in the determination of temperature, salinity, sonic depth, sounding-velocity, and for securing bottom-samples. These include discussions of not only the functioning of the apparatus used, but also of the degree of accuracy attainable. Discussion of the gravity-determinations made in the Pacific is under way, as also of report on the difficulty encountered in the use of the Meinesz apparatus on a surface-vessel.

In connection with the reductions of the Carnegie results, the Department has also had the privilege of using data supplied by the Scripps Institution of Oceanography; the temperatures, salinities, and densities for standard depths have been determined from these and resulting dynamic computations have been made for consideration in the discussion of the Carnegie data.

In meteorology, tables have been prepared of the hourly values of (1) air-temperature, (2) barometric pressure, (3) relative humidity, (4) vapor-pressure, and (5) sea-surface temperature. Group-means for selected areas and harmonic analyses of the means have been completed for (2). Means by areas have been completed for (1), (3), (4), and (5); harmonic analyses have been completed for (5). Manuscript has been prepared descriptive of the sea-surface thermograph and method of reduction of thermograms.

Chemical oceanography

Reduction of data--Vertical-distribution curves have been drawn for pH and PO_4 for all stations, and those for oxygen- and silicate-distribution for stations 130 to 162. Graphs showing all these curves for each station were prepared for publication, as were also sixteen vertical sections showing the distribution of the chemical elements ob-

Table 8—Physical and chemical data and results of dynamic computations for Carnegie deep-sea stations, 1926-1929—Continued

L.M.T. and wire-angle	Depth (D) meters	Observed values: Temperature (t) °C	Salinity (S) o/oo	Density (σ_t)	Oxygen ml/L	Oxygen o/o	Hydrogen ion (pH)	Phosphate (PO_4) mg/m³	Silicate (SiO_3) mg/m³	Interpolated values: Δ	Interpolated values: Temperature (t) °C	Interpolated values: Salinity (S) o/oo	Interpolated values: Density (σ_t)	Computed values: Density (σ_{TP})	Anomalies: Pressure (ΔP)	Anomalies: Dynamic depth (ΔD)	Anomalies: Specific volume (ΔA)
Station 160: November 13, 1929; 10°24' S, 161°23' E; depth bottom, 2614m; weather, ogr; sea, SE; wind, NE 3; good conditions																	
10.77	0	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		0	26.87	35.27	25.69	25.69	0.0000	0.0000	0.00000
	10	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		10	26.87	35.27	25.69	25.69	0.0000	0.0000	
	20	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		20	26.87	35.27	25.69	25.69	0.0000	0.0000	
	30	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		30	26.87	35.27	25.69	25.69	0.0000	0.0000	
	50	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		50	26.87	35.27	25.69	25.69	0.0000	0.0000	
	75	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		75	26.87	35.27	25.69	25.69	0.0000	0.0000	
	100	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		100	26.87	35.27	25.69	25.69	0.0000	0.0000	
	125	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		125	26.87	35.27	25.69	25.69	0.0000	0.0000	
	150	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		150	26.87	35.27	25.69	25.69	0.0000	0.0000	
	200	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		200	26.87	35.27	25.69	25.69	0.0000	0.0000	
	250	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		250	26.87	35.27	25.69	25.69	0.0000	0.0000	
	300	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		300	26.87	35.27	25.69	25.69	0.0000	0.0000	
	400	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		400	26.87	35.27	25.69	25.69	0.0000	0.0000	
	500	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		500	26.87	35.27	25.69	25.69	0.0000	0.0000	
	600	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		600	26.87	35.27	25.69	25.69	0.0000	0.0000	
	700	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		700	26.87	35.27	25.69	25.69	0.0000	0.0000	
	800	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		800	26.87	35.27	25.69	25.69	0.0000	0.0000	
	900	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		900	26.87	35.27	25.69	25.69	0.0000	0.0000	
	1000	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		1000	26.87	35.27	25.69	25.69	0.0000	0.0000	
	1100	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		1100	26.87	35.27	25.69	25.69	0.0000	0.0000	
	1200	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		1200	26.87	35.27	25.69	25.69	0.0000	0.0000	
	1300	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		1300	26.87	35.27	25.69	25.69	0.0000	0.0000	
	1400	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		1400	26.87	35.27	25.69	25.69	0.0000	0.0000	
	1500	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		1500	26.87	35.27	25.69	25.69	0.0000	0.0000	
	1600	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		1600	26.87	35.27	25.69	25.69	0.0000	0.0000	
	1700	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		1700	26.87	35.27	25.69	25.69	0.0000	0.0000	
	1800	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		1800	26.87	35.27	25.69	25.69	0.0000	0.0000	
	1900	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		1900	26.87	35.27	25.69	25.69	0.0000	0.0000	
	2000	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		2000	26.87	35.27	25.69	25.69	0.0000	0.0000	
	2100	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		2100	26.87	35.27	25.69	25.69	0.0000	0.0000	
	2200	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		2200	26.87	35.27	25.69	25.69	0.0000	0.0000	
	2300	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		2300	26.87	35.27	25.69	25.69	0.0000	0.0000	
	2400	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		2400	26.87	35.27	25.69	25.69	0.0000	0.0000	
	2500	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		2500	26.87	35.27	25.69	25.69	0.0000	0.0000	
	2600	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		2600	26.87	35.27	25.69	25.69	0.0000	0.0000	
	2614[a]	26.87	35.27	25.69	3.91	95	8.27	13	0[b]		2614	26.87	35.27	25.69	25.69	0.0000	0.0000	
Station 161: November 15, 1929; 13°04' S, 164°57' E; depth bottom, 4484 m; weather, b; sea, S; wind, N 1-2; good conditions																	
10.41	0	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		0	26.41	35.16	25.69	25.69	0.0000	0.0000	0.00000
	10	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		10	26.41	35.16	25.69	25.69	0.0000	0.0000	
	20	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		20	26.41	35.16	25.69	25.69	0.0000	0.0000	
	30	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		30	26.41	35.16	25.69	25.69	0.0000	0.0000	
	50	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		50	26.41	35.16	25.69	25.69	0.0000	0.0000	
	75	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		75	26.41	35.16	25.69	25.69	0.0000	0.0000	
	100	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		100	26.41	35.16	25.69	25.69	0.0000	0.0000	
	125	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		125	26.41	35.16	25.69	25.69	0.0000	0.0000	
	150	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		150	26.41	35.16	25.69	25.69	0.0000	0.0000	
	200	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		200	26.41	35.16	25.69	25.69	0.0000	0.0000	
	250	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		250	26.41	35.16	25.69	25.69	0.0000	0.0000	
	300	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		300	26.41	35.16	25.69	25.69	0.0000	0.0000	
	400	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		400	26.41	35.16	25.69	25.69	0.0000	0.0000	
	500	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		500	26.41	35.16	25.69	25.69	0.0000	0.0000	
	600	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		600	26.41	35.16	25.69	25.69	0.0000	0.0000	
	700	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		700	26.41	35.16	25.69	25.69	0.0000	0.0000	
	800	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		800	26.41	35.16	25.69	25.69	0.0000	0.0000	
	900	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		900	26.41	35.16	25.69	25.69	0.0000	0.0000	
	1000	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		1000	26.41	35.16	25.69	25.69	0.0000	0.0000	
	1100	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		1100	26.41	35.16	25.69	25.69	0.0000	0.0000	
	1200	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		1200	26.41	35.16	25.69	25.69	0.0000	0.0000	
	1300	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		1300	26.41	35.16	25.69	25.69	0.0000	0.0000	
	1400	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		1400	26.41	35.16	25.69	25.69	0.0000	0.0000	
	1500	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		1500	26.41	35.16	25.69	25.69	0.0000	0.0000	
	1600	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		1600	26.41	35.16	25.69	25.69	0.0000	0.0000	
	1700	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		1700	26.41	35.16	25.69	25.69	0.0000	0.0000	
	1800	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		1800	26.41	35.16	25.69	25.69	0.0000	0.0000	
	1900	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		1900	26.41	35.16	25.69	25.69	0.0000	0.0000	
	2000	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		2000	26.41	35.16	25.69	25.69	0.0000	0.0000	
	2100	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		2100	26.41	35.16	25.69	25.69	0.0000	0.0000	
	2200	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		2200	26.41	35.16	25.69	25.69	0.0000	0.0000	
	2300	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		2300	26.41	35.16	25.69	25.69	0.0000	0.0000	
	2400	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		2400	26.41	35.16	25.69	25.69	0.0000	0.0000	
	2500	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		2500	26.41	35.16	25.69	25.69	0.0000	0.0000	
	2600	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		2600	26.41	35.16	25.69	25.69	0.0000	0.0000	
	2700	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		2700	26.41	35.16	25.69	25.69	0.0000	0.0000	
	2800	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		2800	26.41	35.16	25.69	25.69	0.0000	0.0000	
	2900	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		2900	26.41	35.16	25.69	25.69	0.0000	0.0000	
	3000	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		3000	26.41	35.16	25.69	25.69	0.0000	0.0000	
	3100	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		3100	26.41	35.16	25.69	25.69	0.0000	0.0000	
	3200	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		3200	26.41	35.16	25.69	25.69	0.0000	0.0000	
	3300	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		3300	26.41	35.16	25.69	25.69	0.0000	0.0000	
	3400	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		3400	26.41	35.16	25.69	25.69	0.0000	0.0000	
	3500	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		3500	26.41	35.16	25.69	25.69	0.0000	0.0000	
	3600	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		3600	26.41	35.16	25.69	25.69	0.0000	0.0000	
	3700	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		3700	26.41	35.16	25.69	25.69	0.0000	0.0000	
	3800	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		3800	26.41	35.16	25.69	25.69	0.0000	0.0000	
	3900	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		3900	26.41	35.16	25.69	25.69	0.0000	0.0000	
	4000	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		4000	26.41	35.16	25.69	25.69	0.0000	0.0000	
	4100	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		4100	26.41	35.16	25.69	25.69	0.0000	0.0000	
	4200	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		4200	26.41	35.16	25.69	25.69	0.0000	0.0000	
	4300	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		4300	26.41	35.16	25.69	25.69	0.0000	0.0000	
	4400	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		4400	26.41	35.16	25.69	25.69	0.0000	0.0000	
	4484[a]	26.41	35.16	25.69	3.96	100	8.30	13	0[b]		4484	26.41	35.16	25.69	25.69	0.0000	0.0000	

[a] Piano wire. [b] Value rejected.

Fig. 4—Specimen tabulation Carnegie physical and chemical results as prepared for publication

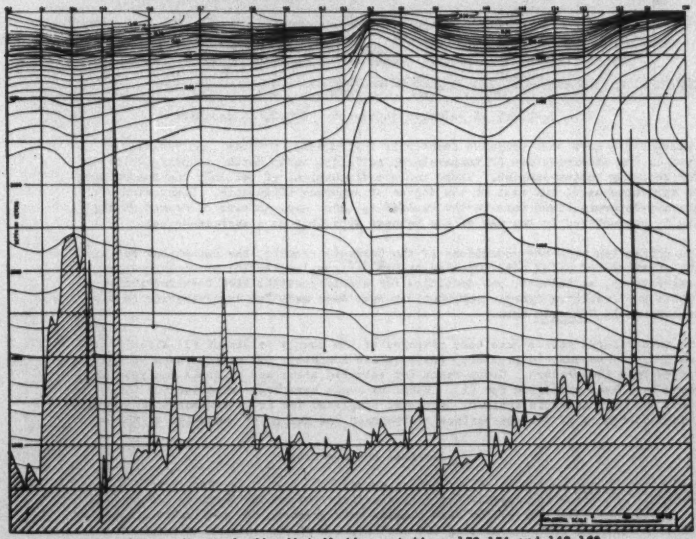

Fig. 5—Sounding-velocity distribution, stations 130-134 and 148-162

served at sub-surface levels along the entire course of the vessel. Tables of observed chemical elements were finally revised and prepared for publication. The phosphate-values have been expressed in milligrams of PO_4, a more logical expression than P_2O_5, as phosphorus in natural waters occurs as the PO_4-ion and P_2O_5 refers to a method of analysis not used for sea-water.

Results--The determinations of dissolved oxygen in the Pacific showed that there were marked differences in the oxygen-content with respect to both locality and depth, but in all cases the following four layers of water were readily recognized: (1) a layer of high oxygen-content near the surface; (2) a photosynthetic zone in which the maximum quantities of oxygen occurred; (3) a transition-zone in which the oxygen-content decreased to a minimum; and (4) a deep layer in which the quantity of oxygen increased slowly with depth but was always considerably less than at the surface.

At most of the Pacific stations the surface-values for oxygen were near 100 per cent, but at stations between 6° and 13° south the surface-concentrations were only from 78 per cent to 89 per cent. These low values could only be accounted for by assuming that at these stations at least part of the water had recently come from depths at which the oxygen-content is normally low.

A layer of minimum oxygen occurred in the Pacific at from 650 to 1,100 meters in latitudes above 20° north, but much nearer the surface in the tropics and especially in the north equatorial drift and in the counter-equatorial current. These differences can be correlated with similar differences in the thermal stratification of the water, but in some cases there was evidence that horizontal water-movements also played a part.

Thus the deep-water of the Pacific was found to contain much less oxygen than that of the Atlantic as determined by others. From this it was concluded that the deep-water of the Pacific has lacked contact with the atmosphere for a longer period than has the Atlantic deep-water, either because the Pacific water flows at a slower rate or is farther removed from its sinking center.

The variation in the quantities of dissolved phosphates in the surface-waters of the Pacific was found to be closely related to the surface horizontal circulation and to vertical circulation. In the north Pacific between 10° and 40° there is apparently a current-system forming a closed circuit and in this region the quantity of phosphate was unusually high, ranging from 80 to nearly 150 milligrams. In this region water-mixing probably takes place to great depths during a considerable part of the year and water from the Bering Sea is probably brought in. In the Pacific south of latitude 10° north the phosphate-content was nearly everywhere higher than in most regions north of this latitude, but was very variable. This may be explained by the existence of vertical currents in this region.

Bottom-samples

Distribution--The 86 bottom-samples secured by the Carnegie (one of the 87 secured having been lost in transit) have been divided and distributed for examination and analysis.

Results--The only complete report thus far made is that by Parker D. Trask of the Frick Chemical Laboratory in the study of nitrogen-content in connection with Project 4 of the American Petroleum Institute Research Program on "The origin and environment of source sediments." Nearly all of the 48 samples submitted to him are pelagic deposits, about one-half coming from the eastern part of the South Pacific, two-fifths from various parts of the North Pacific, and the remainder from the Atlantic and Caribbean Sea. The conclusions drawn by him are briefly summarized as follows:

"(1) Open ocean-deposits contain relatively little organic matter compared with near-shore terrigenous sediments; (2) the organic content of pelagic deposits is fairly uniform over wide areas; (3) the pelagic deposits in the Southern Hemisphere contain less organic matter than in the Northern, the mean nitrogen-content for the deposits of these two areas being 0.03 and 0.07 per

cent, respectively; (4) the sediments of the North Pacific are richer than those of any other oceanic area, averaging 0.08 per cent nitrogen, but the deposits of the South Pacific are poorer than those of all other regions, averaging only 0.03 per cent nitrogen; (5) the data from the eastern part of the Pacific Ocean suggest that on progressing from mid-oceanic areas shoreward the organic content of the sediments begins to become richer at a distance of about 500 miles from the coast, but not until the lower part of the continental slope is reached does it increase markedly; (6) the organic content of near-shore sediments is very variable and is dependent both on supply of organic matter in the overlying water and the configuration of the sea-bottom, being relatively low on ridges and high in depressions, with maximum nitrogen-content about 0.5 per cent; (7) one sample from the base of the continental slope off Peru and one from the Gulf of Panama contain about 0.35 per cent nitrogen and demonstrate that rich deposits are accumulating in these areas."

For the Geophysical Laboratory, Dr. C. S. Piggot reported in March to Dr. Day that he then had made examinations of the radium-content of four of the 28 samples received, these having been selected because they happened to have the greatest amount of material. Geographically these particular samples all came from depths of from 4,000 to 5,000 meters, and all are a long way from land. Dr. Piggot reports radium-content as determined by him in gram X 10^{-12} per gram of sample to be 15.76 at station 153 (7°8 north, 140°4 west), 9.22 at station 156 (3°0 north, 149°8 west), 9.05 at station 128 (40°6 north, 132°4 west), and 9.80 at station 132 (31°6 north, 128°8 west).

Dr. Mann reports that as his study of the diatoms of the 54 Carnegie bottom-samples progresses he is finding very interesting and valuable material. Stations off Japan, Peru, in Guam Harbor, and in the center of the tropical Pacific are proving of unusual interest. New species and many extremely rare species are turning up in these samples. Samples taken near Japan in 4,000 meters of water and in the tropical Pacific (station 156) in 5,000 meters are rich in bottom-diatoms which can live only in shallow water, thus indicating that some very slowly moving currents are carrying these diatom-shells into the abyssal regions of the ocean from some distant shore.

It is hoped that provision may be made for general chemical analyses of the samples to include determinations of CaO, MgO ($CaCO_3$ and $MgCO_3$, hypothetical combinations), SiO_2, $(Al, Fe)_2O_3$, Na_2O, and K_2O.

Biological samples

Distribution--Good progress has been made in the separation of the 1,014 biological samples collected by the Carnegie for distribution to various taxonomists for examination and report. The separation of copepods from the tow-net samples for Dr. C. B. Wilson has been almost completed. Portions of the tow-net samples and small portions of the samples obtained with the plankton-pump are being separated for examination and report on diatoms by Dr. Albert Mann. The other major groups of planktonic organisms such as Siphonophores, Cephalopods, Salps, Crustaceans, etc., are being separated for later distribution to other specialists for descriptive reports.

Results--A manuscript report has been completed on the quantitative plankton-studies of the vertical-net hauls taken in the open Pacific in the area 11° south to 38° north and 124° west to 162° west. This report shows a fluctuation in the plankton-production from north to south in the Pacific which bears no relation to latitude but seems more closely associated with the replenishment of nutrients in the upper layers by the advent of water from the rich reservoirs below.

The manuscript report on "Quantitative phytoplankton studies in the open Pacific Ocean" has been prepared. In this report 303 samples taken with the Pettersson plankton-pump at 114 stations well distributed over 32,000 nautical miles covered by the Carnegie's cruise are discussed. Among the several conclusions resulting from the discussion for this large area of the Pacific the following may be of interest to the Committee: The higher latitudes support a greater production of plankton which may be explained by the lack of nutrients in the upper layers in the lower latitudes where vertical circulation is largely restricted by the greater thermal stratifica-

tion; the maximum oxygen-content occurring below the surface in the photosynthetic zone may not be explained by the activity of diatoms and dinoflagellates.

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OCEANOGRAPHIC WORK OF THE UNITED STATES BUREAU OF FISHERIES

Elmer Higgins

In order that there may be no misunderstanding about the status of oceanographic work of the United States Bureau of Fisheries it must be stated at the very start that the Bureau is not engaged in oceanographic research. The Bureau's work, in the words of the Congressional resolution establishing the United States Fish Commission, is "To prosecute the necessary inquiries with the view of ascertaining whether any and what diminution in the number of food-fishes of the coast and lakes of the United States has taken place; and, if so, to what causes the same is due; . . . and what protection, prohibitory or precautionary measures should be adopted. . . ." In pursuing the necessary inquiries concerning the food-fishes of the country in a thoroughgoing and scientific manner the Bureau's investigators find it essential to make chemical, physical, and other ecological observations, the data of which are of direct interest to the professional oceanographer and which are made available to him from time to time. It is on that account that I am pleased to report upon the oceanographic aspects of the current year's work of the Bureau of Fisheries.

Perhaps the outstanding result of marine fishery-investigations both in this country and abroad during the last two decades has been the recognition of the fact that many of the changes in abundance of fishes that cause the ups and downs in commercial yields are due largely to reproductive success or failure in different years. By reproductive success we mean survival to commercial sizes of sufficient numbers of fish to appreciably affect the stock in the sea. It appears that conditions in certain years are favorable to the survival of the spawning-product of certain species; conditions in other years may result in virtually total mortality of the young which that year might have contributed to the stock. These successes or failures so leave their impress on the population that the yield of the commercial fishery in subsequent years will be large or small depending on whether the year-classes have to a large degree survived or perished.

The prevalence of this phenomenon in the sea fisheries makes it important to examine the conditions that may be responsible for the survival of year-classes. To this end, our investigations on fishes proper have been accompanied by studies of oceanographic conditions in so far as the limited means at our disposal would permit. Results of such studies cannot be forthcoming in a short time. They involve continuous observations over a series of enough years to establish a norm from which departures may be measured and correlated with changes in abundance as measured by the yield of the commercial fisheries in subsequent years. For this reason, progress during the current year must be measured by the degree to which it lays the foundation for future advancement, as well as by the immediate results obtained.

Most of the recent oceanographic work was done by O. E. Sette, in charge of North Atlantic fishery investigations, and his assistants, during the repeated visits of the Albatross II to the mackerel spawning-areas. These areas cover an expanse of offshore-waters extending from North Carolina to Massachusetts, and usually include the full width of the Continental Shelf. Two such cruises were made in May and July 1928, seven during the months of February to July 1929, and twelve during the same season in 1930. From February 5 to October 23, 1930, 259 oceanographic stations were occupied in this area, where 815 serial or individual observations with various apparatus were obtained.

In addition to the regular plankton-collections, which are intended to show only the horizontal distribution, series of hauls have been taken at different levels at eleven stations to determine vertical distribution. The data from these series are expected to facilitate the interpretation of peculiarities in the horizontal distribution and to throw light on the ecology of the plankton-communities.

Eight series of surface drift-bottles were released, a total of 963 bottles. Returns have been so few and their paths so divergent that interpretation of drifts is difficult. It is possible that further light may be cast on the question by additional returns during the coming year.

From analysis of these data we shall have successive pictures of the horizontal distribution of plankton during the months of February, April, May, June, and July--the months that probably are most significant in the life-history of the principal food-fishes of that region. An attempt also has been made to arrive at an understanding of the ocean-drifts over the Continental Shelf between Cape Cod and Cape Hatteras by means of drift-bottles and hydrodynamic calculations. These two taken together indicate that the water-movements in the sector are slight and variable, although generally there is a preponderant drift in the southerly direction. The plankton-collections are being identified and it is hoped that the results may be dealt with from a quantitative standpoint so that correlations may be calculated between the abundance of various forms, including the eggs and fry of fishes and the fluctuations in the commercial fisheries. Inasmuch as we have no oceanographer in this regional staff, the work has not yet progressed far enough to announce the results, but we have had cooperation from oceanographers in the past and it is hoped that by similar cooperation reports on the physical and biological oceanography in this region may be prepared during the coming year.

In the Pacific Ocean observations of oceanographical interest were made in connection with investigations of the pearl-oyster beds in one of the western atolls of the Hawaiian archipelago. In 1928 the Territorial Government of Hawaii made a request

for an investigation of the pearl-oyster beds discovered the previous year in Pearl and Hermes Reef, a small lagoon located about 1,100 miles in the west northwestern direction from Honolulu. Because of a lack of funds the project could not materialize until the Navy Department consented to loan a vessel for the purpose and the Territorial Government appropriated a small sum to cover part of the expense.

On July 15, 1930, Dr. Paul S. Galtsoff, in charge of the expedition, sailed aboard the U.S.S. Whippoorwill from Pearl Harbor, Territory of Hawaii, and arrived at Pearl and Hermes Reef on July 19, 1930. The ship was anchored outside the lagoon about 13 miles from the Southeast Island, where headquarters were established. Pearl and Hermes lagoon is an atoll about 18 miles long and 12 miles wide. It is partially surrounded by a narrow strip of coral reefs, which embrace it on the east, south, and southwest leaving the northern and northwestern sides unprotected. A series of islands, most of them merely sand bars, extends from the northeastern corner along the eastern and southern sides of the lagoon. The lagoon itself comprises a maze of small reefs and channels, with the depth of water varying from a few inches to 104 feet. The reefs growing inside the lagoon are made up by the finger-like coral, Porites. While live corals grow on the very steep slopes of the reefs, the flat tops are covered with very soft sand and old broken corals. Pearl-oysters are found almost exclusively among the corals on the slopes of the reefs at the depth from 10 to 47 feet, but below that the bottom is covered with sticky coral mud unsuitable for pearl-oysters.

Inasmuch as no detailed hydrographic survey of Pearl and Hermes Reef has ever been made, considerable time was spent in mapping the area and determining the exact position of the islands. This part of the work was carried out by Lieutenant M. M. Nelson, Commanding Officer of the U.S.S. Whippoorwill, who made astronomical observations and determined the longitude and latitude of the islands, the position of which was found to be slightly different from that shown on the charts. Three high signal-towers built on the Island were carried on the motorboat and placed in shallow water in the middle of the lagoon. They were supplied with platforms from which the location of pearl-oyster beds, marked by buoys, was determined by means of compass and range-finder.

Oceanographical observations consisted in taking daily temperature-readings and in determining the salinity of the water. During the period of observations from July 22 until August 23 the temperature of the water increased from about 25° C to 28°5 C. The range of daily fluctuations of temperature was about 1° C, the higher temperature always occurring in the afternoon. The salinity remained approximately constant, fluctuating around 36 per mille. A detailed study of the distribution of the salinity in the lagoon shows the increase in concentration of salts in a well-protected section of the lagoon close to the sand-bars and islands. From a study of the distribution of reefs and coral-mud bottoms the deduction can be made that their relative position in the lagoon is due to the destructive action of northeast winds and storms which cause the accumulation of sand and mud in the southern section of the lagoon. An important role in the formation of coral-mud is attributed to a large holothurian, Stichopus, which abounds in the lagoon.

For the examination of pearl-oyster beds three divers were employed. Because of the irregular distribution of the beds the total number of the present oyster-population of the lagoon could not be determined. However, from the data obtained during the investigation it is possible to determine the relative abundance of oysters, that is, the number of oysters found by the average diver during a given period of time.

Such biological observations were carried out at 70 stations distributed over the whole area of the lagoon, and from an analysis of the data many facts concerning the life-history of the pearl-oyster have been obtained that will serve as a basis for future protection of the stock.

Pearl-oysters of Pearl and Hermes Reef produce valuable shells (mother of pearl) and bear large numbers of pearls. It has been estimated that since 1927, when pearl-beds were discovered, not less than 100 tons of shells (about 106,000 oysters) were taken from the reef. There is no doubt that without protection the beds will be completely wiped out in a short time. However, the Governor of the Territory has issued an order prohibiting the taking of pearl-oysters from any locality within the jurisdiction of the Territorial Government.

The expedition brought back from Pearl and Hermes Reef 310 live pearl-oysters, which were planted in Kaneohe Bay near Honolulu. It is hoped that these oysters will form a nucleus of the first American pearl-oyster farm by establishing themselves in the new environment, which is suitable for their growth and propagation. The expedition also brought back a considerable collection of bottom-samples, corals, crabs, shells, sponges, and interesting photographs of coral-reef fishes taken under water.

U. S. Bureau of Fisheries,
Washington, D. C.

OCEANOGRAPHIC WORK OF THE BUFFALO MUSEUM OF SCIENCE IN 1930

Charles J. Fish

As reported at previous meetings the scientific work of the Buffalo Museum of Science is for the most part carried on jointly with other institutions. This policy of coordinated effort making possible correlation of results and elimination of duplication has proven very satisfactory in five such programs in which the Museum has participated during the past three years. During the past year, members of the scientific staff have engaged in one cooperative oceanological program and several special problems carried on by individual members.

Another feature of the Museum's policy which I should like to mention at this time is the consideration of fresh water as well as marine conditions in studying the biology of aquatic life. It is regrettable that there has to date not been a closer relationship between marine oceanologists and investigators of such large inland bodies of water as the Great Lakes. Heretofore each group has carried on its investigations with too little regard for the other, and utilizing methods, particularly in the biological field, which yield non-comparable results.

Being situated on the shores of one of the Great Lakes the marine workers of the Buffalo Museum have had an opportunity to devote a portion of their time to investigations of these waters, and during two seasons of intensive field-work have been impressed by the fact that many of the problems confronting the oceanologist find their counterpart in the Great Lakes. The latter offer a convenient laboratory where many obvious complicating factors of the open sea are eliminated. It is not probable that many individuals will find it desirable to carry on investigations in both fresh- and salt-water, but it is hoped that more standardized methods will be adopted in order that the two groups may keep better posted on each other's work and thus be enabled to better utilize those results which have general biological application.

Papers completed--A publication by Marie P. Fish on "Contributions to the natural history of the Burbot Lota maculosa (LeSueur)" describing its developmental stages and distribution in Lake Erie has appeared (Bull. Buffalo Soc. Nat. Sci., v. 15, No. 1). As this is the only fresh-water member of the cod-family, its life-history is of special interest.

A monograph on the early life-histories of sixty species of Lake Erie fishes, together with seasonal and horizontal distribution-records has also been completed by Marie P. Fish and is being submitted for publication by the Bureau of Fisheries. This paper contains 137 figures illustrating developmental stages. The materials were obtained partly from the records and collections of the Cooperative Survey of Lake Erie in 1928-29 and partly from a collection of approximately 10,000 larval specimens taken in the western part of the Lake by the Ohio Division of Fish and Game. For the completion of this work the State of New York this year appropriated $2,100 to defray the expenses of compiling the data and preparing the figures, and an additional contribution of $1,800 toward its publication. Included in this report are several so-called "Arctic relic" species of which Triglopsis Thompsoni is of special interest. This species is a close relative of the marine Circumpolar Genus Oncocottus.

The second part of the report on the two-years' work of the Cooperative Survey of Lake Erie, the program of which was described last year, will be submitted on or about August 1, 1931, for publication by the Bureau of Fisheries. It will contain papers by individual authors on the physical hydrography, topography and sedimentation, chemistry,

bacteriology, phytoplankton, zooplankton, and general limnology. Four papers by members of the Museum staff will be included in this report.

An investigation of the phytoplankton of seventeen lakes in central New York State, based on monthly and in some instances semi-monthly observations extending over a period of two years, by P. R. Burkholder, is in press and will appear about June 1 (Bull. Buffalo Soc. Nat. Sci., v. 15, No. 2). Seasonal, vertical, and geographical distribution of 435 species of phytoplankton have been recorded together with temperature, transparency, dissolved-oxygen, free carbon-dioxide, phenolphthalein alkalinity, methyl-orange alkalinity, and hydrogen-ion concentration determinations.

A paper on "The ammonia content of sea-water," based on observations in 1930 in Frenchmans Bay by H. R. Seiwell, has been completed and submitted for publication in the Journal of Ecology. He has also completed a paper on "Specific-gravity determinations in inshore-waters of the Gulf of Maine."

A report on "The Phyllocaridians of the Arcturus Expedition" has been completed by the author. Of interest is the extension of the distribution of the Antarctic species Nebaliopsis typica. But one catch north of latitude 39° south had previously been reported, that of the Valdivia Expedition in the Atlantic in latitude 0° 20' north from a vertical haul of 3,500 meters. The present specimen from the Pacific in latitude 4° 50' north and longitude 87° west (approximately sixty miles south of Cocos Island) in a haul from 1,534 meters extends the deep-water distribution of this species far into the Pacific. A new species of Nebaliopsis, the second of the genus to be described, was also obtained by the expedition in the eastern Pacific in a haul from 3,476 meters in latitude 0° 42' south.

Reports nearing completion

Byrd Antarctic Expedition--A study of the phytoplankton and zooplankton material taken by the Byrd Antarctic Expedition is now being made by R. F. Shropshire who made the observations and is now a member of the scientific staff of the Buffalo Museum. The collections consist of two series of surface-filtrations comprising over 100 samples extending from New Zealand to the Bay of Whales. One series was taken from December to March 1928, and repeated during the same season in 1929. The collections were obtained by passing a continuous flow of water from one of the ship's pumps through a filter of No. 20 silk bolting-cloth.

In addition there is a very representative series of meter-net collections from the Antarctic Ocean and Ross Sea, and about 20 samples of plankton obtained by centrifuging water melted from dark streaks in sea ice-floes. To date approximately 50 species of diatoms have been obtained from the melted ice, all of which are characteristic Antarctic species. A few copepods obtained in this material to date have been previously described from Arctic waters. It is hoped that the results will prove a contribution to present knowledge of the nature and distribution of the plankton of this area.

Gulf of Maine investigations--The oceanological investigations begun in 1929 were continued during the summer of 1930 under the auspices of the following institutions: Mount Desert Island Biological Laboratory, Brown University, and the Buffalo Museum of Science. The staff consisted of eleven members representing the three institutions.

The primary object of the investigations was to study quantitatively and qualitatively the production and distribution of the pelagic fauna and flora in the region of Frenchmans Bay. It was hoped that the biological results together with the physical and chemical data might also throw some light on another problem, namely, if and to what extent the fertility of this area is due to strictly local conditions, or to what extent it may be influenced by the peculiar hydrographic conditions at the mouth of the Bay of Fundy. It has been suggested that local sources of food-supply are not sufficient to maintain the rich animal- and plant-communities of the bays along the Maine coast, and instead of contributing to the fertility of offshore-waters they may really be consumers, depending to a certain extent for their support upon foodstuffs transported by the westerly drift about the margin of the Gulf. If such a condition is found to exist, any alteration of the vital areas to the eastward, such as the proposed damming of Passamaquoddy Bay, might exert more than a purely local influence.

Investigations in areas of considerable river-outwash, such as Penobscot or Casco bays, would not yield results applicable to the coast-line of the Gulf as a whole. Frenchmans Bay with its negligible drainage (average salinity in summer 32.05 to 32.48 o/oo) seemed to offer a much more favorable location in which to begin. Even the Sullivan River, the major source of outwash, was brackish at its source and contained a purely marine plankton-community.

Investigations in 1929 covered Penobscot, Blue Hill, Frenchmans, and small bays as far east as Petit Menan but in 1930 the work was concentrated for the most part in Frenchmans Bay where sixteen cruises were made between June 24 and August 20. Temperature, salinity, phosphate and nitrate analyses, nannoplankton, phytoplankton, and zooplankton observations were taken at selected stations throughout the summer.

Almost from the beginning the chemist, Dr. Rakestraw, encountered wide variations in the concentrations of phosphate and nitrate not only in neighboring localities but within short intervals of time in the same locality. It became evident that any attempt to correlate these rapid fluctuations with diatom-production was obviously out of the question.

The complicating factor is introduced, I believe, by the extensive benthonic weed-beds which cover a large portion of the bay. With an average depth of 30 meters there are many acres of Laminaria and Fucus which due to their proportionate volume apparently eliminate any possibility of a correlation of chemical values with diatom-production. As the region of Frenchmans Bay thus proved a particularly unfavorable location in which to carry out a program of this sort, the biologist, Dr. Burkholder, and I devoted our attention to the original biological objective, a quantitative and qualitative determination of the production and vertical distribution of the pelagic flora and fauna of the bay. The physical and chemical work carried on by Dr. Rakestraw and Mr. Seiwell will be discussed by the latter later in this program.

The phytoplankton was found by Dr. Burkholder to be abundant throughout the summer, increasing markedly in late August. The maximum volume occurred usually at ten meters where on August 14, 43.2 cc per cubic meter was taken. Below twelve meters plant-plankton was scarce. Frenchmans Bay with relatively little influx of fresh-water supported during the season a larger volume of phytoplankton than Penobscot Bay where low salinity-values indicated a comparatively large contribution of fresh-water from the Penobscot River.

The zooplankton-life of Frenchmans Bay in summer consists of two communities, a typical boreal neritic summer group, and a cold-water community (Calanus-Thysanoessa) characteristic of the open Gulf at all seasons. The former during the day extended from the surface to about 45 to 50 meters, some forms such as the Cladocera and pelagic eggs remaining always at or near the surface. The bulk of the species, however, were concentrated near their lower level. Below 50 meters and quite distinct, the Calanus community was found everywhere in the Bay when the water was of sufficient depth. It was not possible to make sufficient evening hauls to determine definitely the extent of vertical migration at night, but sufficient catches were made to indicate that a part at least of the deep-water forms join the upper community in the surface-layers after dark. Some evening net collections contained as much as 85.3 per cent of lower-level species.

A striking characteristic of the neritic plankton of Frenchmans Bay, both in 1929 and 1930, was the comparatively small number of species of invertebrate and vertebrate larvae taken by the nets, and the extent of the breeding-season. Contrasted with areas to the west, such as Woods Hole, where during the summer the plankton contains a large variety of larval forms with very limited seasonal duration, Frenchmans Bay yielded a very small number of species, almost all of which were found at the beginning of the season (June 24) and occurred continuously throughout the duration of the observations.

Another apparent feature of the locality is the failure of many invertebrate and some vertebrate species to survive long after birth, if in fact they hatch at all. For some reason, perhaps temperature, development does not seem to be successful. It would appear that the waters must be stocked by immigration of adults from other areas.

Such a condition has been reported from the Bay of Fundy but was not known to exist as far west as Mount Desert Island. There is some evidence that Mount Desert Island may form the western boundary and that in Blue Hill Bay more favorable conditions exist.

Buffalo Museum of Science,
Buffalo, New York

OCEANOGRAPHIC PROGRAM AT THE UNIVERSITY OF WASHINGTON

Thomas G. Thompson

The various phases of marine studies at the University of Washington were grouped together under one head about a year ago, upon the recommendation of Dr. M. Lyle Spencer, president of the University of Washington, to the Board of Regents. The new organization is known as the Oceanographic Laboratories of the University of Washington, and includes the former Puget Sound Biological Station located at Friday Harbor in the San Juan Archipelago. The main laboratories are situated on the campus of the University on the shore of Lake Union. Ready access to the sea is obtained through the Lake Washington ship-canal.

The field-laboratories, located at Friday Harbor, are composed of a group of fireproof buildings constructed of hollow tile. There are eight buildings devoted respectively to physical oceanography, oceanographical chemistry, marine plant-physiology, embryology, and invertebrate zoology. One building is used as a general research-laboratory and another serves for a stockroom and storage-purposes, while the eighth cares for the commissary and the library. Courses are given in the field-laboratories for graduate students during the summer, but the chief emphasis is on the various phases of research. These laboratories are equipped so that research may be carried on during the entire year by a limited number of investigators. One of the members of the staff, the assistant director, resides on the grounds together with the curator of the laboratories.

The third part of the organization consists of work actually done on the sea. The Rockefeller Foundation has appropriated the sum of $10,000 a year for a period of five years for the purpose of chartering a boat. In addition, a sixty-foot salmon-trawler, equipped with apparatus for dredging, for net-hauls, and water-sampling is chartered and serves the field-laboratories during the summer months. The Navy Department has agreed to turn over a small thirty-five-foot motor-boat to the Laboratories for seasonal studies of the variation of the chemical composition of the waters and plankton in Puget Sound. This boat will be equipped with a small laboratory and apparatus for taking samples and plankton-tows.

The staff of the Laboratories at present is composed of one physicist, Dr. C. L. Utterback; two chemists, Dr. Thomas G. Thompson, the director, and Dr. R. J. Robinson; two botanists, Dr. George B. Rigg and Mr. Lyman D. Phifer, assistant director; and two zoologists, Dr. J. E. Guberlet and Dr. R. C. Miller. As funds, facilities, and equipment become available, it is planned to add a bacteriologist, a geologist, a physiologist, and another physicist to the staff.

There were three reasons for locating the main laboratories on the campus: (1) A university-contact in all its phases is assured the majority of the members of the staff; (2) contact is always assured with promising students in the several fields of science, who might be directed into oceanographic work; (3) the services of a large and adequate library are always available.

It is the opinion of the members of the staff that the best advances in oceanography can only be made through the fundamental sciences and that increase in oceanographic knowledge is dependent upon the advances of these fundamental sciences. Thus the members of the staff have their research-activities centering around oceanography with a seminar in some phase of the subject. Their teaching, however, is in some phase of their particular specialty in the fundamental sciences. One-third to one-half the time of each member is devoted to oceanographic research and the remainder to teaching in some particular branch of the fundamental sciences.

At present there are about twenty graduate students conducting research under the direction of the members of the staff of the Laboratories. The immediate contacts in Seattle are particularly favorable for stimulating oceanographic work as there are located in this city the laboratories of the International Fisheries Commission and the northwest headquarters of the United States Coast and Geodetic Survey. At present the laboratories of the United States Bureau of Fisheries are under construction. Furthermore, the varied maritime activities of Seattle render a ready source of information, advice, and the immediate purchase of supplies and equipment.

The staff of the laboratories enjoys the stimulation and encouragement of other stations located on the Pacific, particularly the Scripps Institution of Oceanography, the Pacific Station of the Biological Board of Canada, and the Hopkins Marine Station.

The Oceanographic Laboratories received the sum of $10,000 from the University of Washington for the purchase of additional material for the library, the sum of $200,000 from the Rockefeller Foundation for the erection and equipment of the campus laboratories, in addition to the sums previously mentioned for the maintenance of a boat. The State of Washington appropriated the sum of $50,000 for additional equipment for the laboratories in Seattle and Friday Harbor.

Abstracts of various publications appearing during the past year, together with outlines of investigations in progress at the present time are not covered here because they compose part of the report to be presented to this meeting by Dr. Vaughan.

Considerable work has been done along the lines of physical and chemical oceanography in cooperation with the International Council for the Exploration of the Sea. Samples of water collected by the recent Dana Expedition are enroute to the Laboratories. At the suggestion of the British Admiralty, various samples are being collected by the British, Australian, New Zealand Expedition, which will be studied in the Laboratories. Arrangements have recently been made with Dr. Sverdrup for the preliminary studies of the waters collected by the proposed Wilkins-Ellsworth Trans-Arctic Submarine Expedition.

The researches in progress at present include the studies in the radioactivity of sea-water, light-penetration, preliminary studies in current-measurements, determination of ionic ratios of the major components of sea-water, the study in the development of methods for the determination of substances occurring only in minute quantities in the water, researches in phytoplankton and zooplankton, studies of the teredo, the relation of colloidal material in algae and the relation of this material to the nature of marine plants and the development of larval forms.

The field of activities of the Laboratories will include the Puget Sound and the San Juan Archipelago area, regions off the coast of the State of Washington and Alaska, and the northeast Pacific.

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PROGRESS IN GULF STREAM TEMPERATURE-INVESTIGATIONS

Charles F. Brooks

Franklin observed Gulf Stream temperatures a century and a half ago in order to identify the strong current of the Gulf Stream that meant so much to navigators in the days of slow sailing-vessels. The subsequent investigations of James Rennell (1832), Lieutenant M. F. Maury (1842), and the United States Coast and Geodetic Survey, beginning with Professor A. D. Bache in 1844 and culminating with Lieutenant J. E. Pillsbury in the late '80s, were also primarily in the interest of navigation, though the studies were in a detail that exceeded the immediate need (1). The same is true of the later investigations by the United States Coast and Geodetic Survey and by the International Ice Patrol. The United States Bureau of Fisheries, interested in the distribution of life in the sea, became an important investigator of Gulf Stream temperatures. Observations of Gulf Stream temperatures were also made by M. P. Idrac

for M. Georges Claude to determine the differences in temperature available for the operation of a low-pressure steam-engine. Among the purely scientific expeditions that have observed Gulf Stream temperatures may be mentioned the Challenger Expedition, the Dana Expedition, and the cruises of the Carnegie.

The first proposal to study Gulf Stream temperatures in the interest of seasonal weather-forecasting seems to have been made by Colonel E. Sabine in 1822 and again in 1846. Unusually warm and stormy weather in northwest Europe in these years were ascribed by him to an excess of heat in the Gulf Stream, and he urged observations on the American side of the Atlantic, especially in the Gulf of Mexico and Straits of Florida, so that the coming of such warm waters and related stormy weather might be anticipated (1). Pillsbury (1) and Hans Pettersson (2) likewise urged such observations. Helland-Hansen and Nansen (3), however, finding that sea-surface temperature-departures in the North Atlantic were closely related to the immediately preceding departures of winds from normal directions and strengths, questioned the possibility of forecasting seasonal weather in northwest Europe from departures in Gulf Stream temperatures near America. Certain studies of the author (4), however, seemed to show a definite relation between departures in Gulf Stream temperatures and coldness and storminess in the northeastern United States, and also indicated some relation between Gulf Stream temperature-departures and those in the eastern Atlantic months later. Obviously what was required was a major statistical investigation based on the innumerable ships' logs collected since Maury's time; but the magnitude of the task has permitted scarcely more than a sampling. Three examples will suffice. To make a study of the sea-surface temperatures in the southwestern North Atlantic I had placed on weekly maps all the data available in the United States Weather Bureau and the United States Hydrographic Office for the three months January to March 1924. To enter the 11,000 reports required four or five months' time of a rapid worker. The Scripps Institution of Oceanography has just compiled sea-temperatures from logs for 50 one-degree squares off San Francisco, back for about 32 years. This took six months--more years were not added for the gleanings from earlier years were beginning to cost far too much for the value of the additional data. The United States Weather Bureau has compiled sea-surface temperatures by quarter-months from the Caribbean Sea and the western portion of the Straits of Florida from 1919 to the present, and began this year to publish monthly means and their relation to the normals (5).

Over a period of ten years the frequency of unusually wet months in districts of the eastern United States has shown a remarkable parallel to these Caribbean temperatures for a few months earlier, the greater frequencies of wet months following the higher Caribbean temperatures as shown by Figure 1. Caribbean temperatures should be compiled for several decades in the past to see whether this is a true relationship. The Caribbean temperatures for Figure 1 were compiled by the late P. G. Tingley (12) and by Giles Slocum (5) and made available to the author by the United States Weather Bureau. The wet-months data were compiled for district-departures published in the Monthly Weather Review, each of the districts being given equal weight (for simplicity). The twelve districts used were: New England, Middle Atlantic States, South Atlantic States, Florida Peninsula, East Gulf States, West Gulf States, Ohio Valley and Tennessee, Lower Lake Region, Upper Lake Region, North Dakota, Upper Mississippi

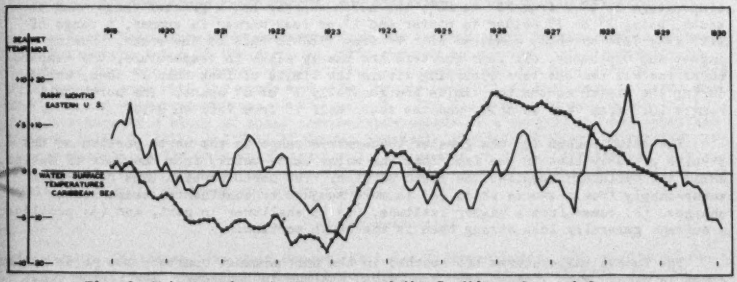

Fig. 1--Water-surface temperatures of the Caribbean Sea and frequency of wet months in the eastern United States, 1919-30

Valley, and Missouri Valley. Only those departures of +1.00 or more inch were used, and each departure of this amount or more was simply counted as one case. The values plotted are floating 12-month sums of departures from the 10-year averages for 1920-29.

After my 1924 maps with their 11,000 observations were complete it was found hardly anything could be done with them, for neighboring values differed so markedly, even for the same days. The reported data were subject to appreciable error. Studies of these errors at sea (6, 7) indicated that they were partly systematic but very elusive, being the combined result of so many sources of error. While temperatures reported in the Caribbean were fairly consistent, those in the Gulf Stream off Cape Hatteras had an average depression of some 5° F below the probable true surface-temperature, and ranged over 20° for the same water. Here, in the region most needing investigation, the temperatures appeared least reliable. If the departures of sea-temperature from year to year were several times as large as the errors in the temperature-observations a statistical investigation on a large scale could be undertaken with reasonable hope of significant results; but the departures from year to year were found to be less than the average observational errors. Therefore, automatic registration of the temperatures of the surface-layer by means of accurate thermographs was indicated as the only practicable way to get sufficiently accurate data and enough observations to make possible the accurate mapping of the warmer and cooler waters in and about the Gulf Stream.

Thermograph-observations in the western Atlantic were instituted several years ago by the French on the training-ship and floating-observatory, the Jacques Cartier. An extensive program of observations by thermograph was inaugurated in 1928 by Clark University and the United States Weather Bureau, and was extended in 1927 and 1928 by the Canadian Meteorological Office, the International Ice Patrol, and in 1928 and 1930 by the American Meteorological Society. In 1929 and 1930 the Furness Bermuda Line and the Munson Line contributed thermographs (8). And now the United States Weather Bureau has obtained a thermograph for the S.S. Cuba of the Peninsular and Occidental Steamship Company on the route Port Tampa, Key West, and Habana. The Scripps Institution of Oceanography is purchasing two more instruments for Panama Pacific Line steamships, and the Brazilian Traction, Light, and Power Company, Limited, of Toronto, is about to install thermographs on lines between New York and southern Brazilian ports.

A reduction of two years of records across the Straits of Florida which has already been published (9, 10) revealed the following, which is quoted or abstracted from the Monthly Weather Review: The surface-waters of the Gulf Stream in the Straits of Florida are diverse in temperature and are subject to considerable variations from day to day. Much of the interdiurnal variation is closely related to the weather, especially the wind, which disturbs the surface. Characteristic differences in the general shape of the surface temperature-profile across the Straits seem to arise from the frequent occurrence of cool northerly winds in winter, reducing the surface-temperatures on the Key West side, and from the prevalence of warm southeasterly winds in summer which raise the temperatures there.

While for the width of the Straits as a whole the annual range of sea-surface temperature is 9° F from 76° to 85°, the north quarter has a greater range than the south, being 2° or 3° colder in winter and 1° or less warmer in summer, a range of 11°7 from 75°4 to 85°1, compared with 7° from 77°5 to 84°5 in the south. During August and September, all four quarters are nearly alike in temperature, the temperatures for all the quarters occurring within the limits of less than 1° then, while during the winter months the limits are generally 4° or 5° apart. The north half ranges 10°7 from 74°3 to 85°0, and the south half 7° from 77°5 to 84°5.

The chief reason for the greater temperature range in the north portion of the Straits probably lies in the fact that the water comes mainly from the Gulf of Mexico, while the Caribbean supplies the south portion. The north portion thus receives a water-supply from a source which (a) is more subject to continental temperature-changes, (b) comes from a higher latitude, (c) is shallower in part, and (d) provides a current generally less strong than in the south portion.

The lowest temperatures are reached in the northernmost quarter; the major minimum comes in March, with a secondary (cool-wave) minimum in December. The northernmost quarter also reaches the highest temperature, its maximum coming in late July or early

August. Because the record is broken in these two months in both years, it is difficult to state an exact maximum, as it might have been reached during the time when the car-ferry was making no trips.

The variations of sea-surface temperature in the Straits of Florida are the joint product of the following five major factors: The seasonal course of insolation, the weather over the Straits, irregular changes in the temperatures of waters flowing into the Straits, variations in the relative contribution from the Gulf of Mexico and from the Caribbean Sea direct, and local turbulence or upwelling. The seasonal course of insolation does not dominate the sequence of temperatures from week to week, the continuity of trend upward or downward being only 48 to 57 per cent. Variations in the weather, particularly in sunshine, air-temperature, and wind, however, are closely paralleled by the trends of Gulf Stream temperature, as already indicated in the summary of changes in the profile of temperature across the Straits. Air-temperature at Key West, particularly daytime temperatures, which are more representative of the general air over the region and which in a way integrate the effects of sunshine and wind, are followed by Gulf Stream temperatures in their ups and downsfrom week to week an average of 81 per cent of the time. The variations in Gulf Stream temperatures, particularly the nighttime temperatures, which through thermal convection represent a considerable layer of water, are much smaller than those of the air-temperature. In fact, even after several degrees rise of surface-temperature by day, the night temperatures return to the same values as on the preceding night.

Not all the parallelism between weather and Gulf Stream temperature is ascribable to the immediate effect of the local weather, for the local weather is a sample of the weather over a wide region, the effects of which may continue to be felt for some time as the water comes from the west. A north wind in winter will be attended by lower air-temperature, it will chill the water, and also it will drive cooler waters southward, and by stirring bring the colder deeper waters to the surface. The temperature-change in the Gulf Stream may be much greater than the immediate chilling of the water by the wind, for the drift and the deeper stirring may not only contribute cooler water from the Gulf of Mexico but also greatly increase the proportion of the Gulf Stream made up from the Gulf's contribution.

If the effects of weather on Gulf Stream temperatures ceased when the Gulf Stream entered the Straits of Florida the usefulness of temperature-observations on the Key West to Habana line would be very great indeed, but this great stream continues to be subject to the vicissitudes of the weather. Changes in the speed of the stream, owing to changes in atmospheric pressure-distribution and other causes, and the degree to which the warm surface-water is stirred into the body of the stream vary the heat-delivery to the Atlantic and determine its earlier or later availability to the atmosphere. Quiet weather and little stirring produce high surface-temperatures, little storage of heat, and ready discharge in the western Atlantic. Windy weather and much stirring produce moderate surface-temperatures, much storage of heat, and reduced immediate availability of this heat. At a previous meeting I cited the cooling effect of a gale in April 1929 (11). To what degree observations in the Straits of Florida may indicate subsequent temperatures off Cape Hatteras or the Grand Banks may be determined from thermograph records now available.

A large body of records, covering from one to five years on numerous lines crossing the western third of the North Atlantic may now be studied. An opportunity is presented for mapping temperature-distribution by weeks and for comparing the changes from week to week with the winds and other weather-conditions that have occurred over the area and with temperatures up the current. The Woods Hole Oceanographic Institution has adopted a study of these thermograph-records as a project and has appointed Messrs. Keith B. Allan and Phil E. Church, graduate students at Clark University, research associates for this investigation in the summer of 1931. Application of western Atlantic Ocean surface-temperatures to possible seasonal weather-forecasting must await the results of these and other studies.

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PRELIMINARY REPORT ON THE RESULTS OBTAINED BY DUPLICATE MEASUREMENTS OF SPECIFIC GRAVITY OF SEA-WATER BY THE KNUDSEN AND PLUMMET METHODS

H. R. Seiwell

During the summer of 1930 in connection with certain studies of the fertility of coastal waters, an investigation of the reliability of the assumption that the halogen salts bear a definite relation to the total salt-content of coastal waters, and consequently the specific gravity, was carried out. Observations were made on the waters of two bays bordering the Gulf of Maine: Frenchmans Bay with a salinity range of about 31.80 o/oo to 32.48 o/oo (June to August 1930) and Penobscot Bay with a salinity range of 0.46 o/oo to 32.29 o/oo (August 21 to 24, 1930).

The density (σ_ρ) of each sample of water was determined by two distinct methods: (1) By Knudsen's method of chloride-titration and calculation of σ_ρ by means of Knudsen's hydrographical tables, and (2) by ascertaining the weight of a calibrated glass-plummet in the water-sample at a known temperature. The former method gives a value of σ_ρ based on the asumption that the halogen salts bear a definite relation to the total salts dissolved in sea-water ($\sigma_\rho = -0.069 + 1.4708\ Cl - 0.001570\ Cl^2 + 0.0000398\ Cl^3$) and the latter density-value is based directly on the total salt-content of the water irrespective of the proportions in which the various salts are dissolved. Hence, the latter density-value is regarded as the actual one and a comparison of the two series of density-values indicates the validity of assuming a constant relationship of halogen to total salt dissolved in the coastal waters studied.

The plummet- or "sinker"-apparatus, used for direct determination of density, was similar in essential detail to that previously described by Michael and McEwen and Cummings of Scripps Institution of Oceanography. An Ainsworth chemical balance, sensitive to 0.1 milligram, was used to determine the weight of a glass-plummet suspended in the sample from its left-hand arm. A calibrated thermometer, reading to tenths of a degree, indicated the temperature of the sample at the time of weighing. The determinations were carried out between temperatures of 19° and 24°.

Specific-gravity determinations were made on the samples a few days after collection. The water was stored in seasoned glass bottles and evidence was obtained to show that the short periods of storage did not appreciably alter the specific-gravity result. Possible objections to the direct determination of density of sea-water, pointed out by some investigators, were found to produce only very small errors in the final result so as not to affect the verity of the conclusions drawn. The average error in the specific-gravity result determined by the plummet-method was about the same as the error when determined by chlorine-titration, namely, about two parts in one hundred thousand.

In 39 of the 43 duplicate specific-gravity (σ_0) determinations on the water of the Penobscot Bay and River, the density as determined by chloride-titration was 0.00000 to 0.00015 higher than that determined directly by the plummet. In the four exceptions the plummet-densities ranged 0.00001 to 0.00003 higher. There is no apparent correlation of density-discrepancy with salinity of the sample, except that when the agreement between the two density-values was good (0.00003 or less) the water-sample was usually in the higher range of salinities (above 31 o/oo).

On the other hand, the 13 duplicate density-determinations on the waters of Frenchmans Bay were in much better agreement. In this latter series all but one of the plummet-determined densities were lower than the densities calculated from chloride titration, and in only one case was the difference in σ_0 as great as five parts in one hundred thousand, the average σ_0 determined by chloride-titration was 0.00002 higher than σ_0 measured directly by the plummet-method.

The fact that the actual (plummet) density of the water of Penobscot Bay was 0.00000 to 0.00015 lower than the density determined indirectly by titration of the chloride seems to indicate that in general the proportion of chloride in the total salt dissolved in the water of this Bay is higher than is characteristic of normal sea-water (S o/oo = 1.8050 Cl + 0.030). In other words, the chloride to total salt ratio is higher than normal, or the amount of total salt dissolved in the Bay water is lower than that indicated by titration of the chloride would be for normal sea-water.

Thus, the chloride to total salt ratio (Cl/S) appears to be represented by a larger number in the natural diluted water of Penobscot Bay than is characteristic of normal sea-water. From certain considerations that is just the reverse of what would be expected for natural diluted sea-water; the number representing the chloride to total salt ratio of the sea is many times greater than it is for fresh-water rivers. On the basis of the analysis of twenty rivers of the Atlantic slope (see F. W. Clarke, Bull. 770, U.S.G.S., 1924) the average chloride-total salt ratio of river water has been computed to be less than one-tenth of that for normal sea-water (Cl = 5.08 per cent of the total salt). Consequently, when sea-water is diluted with river-water we should expect the chloride to total salt ratio to be slightly less than normal, whereas in Penobscot Bay the reverse was found to be the case.

The chloride to total salt ratio of the more saline (less diluted) water of Frenchmans Bay was more nearly in accord with that characteristic of normal sea-water although here again it was slightly higher than normal.

The variations in the chloride to total salt ratio of the coastal waters under discussion are in accord with variations of chloride-ratios with other constitutents found for other coastal waters. In all cases an excess of chlorine-ions appears to be indicated as being present in natural diluted waters, whereas, from the chemical composition of the sea, fresh-water lakes and rivers, a slight decrease of chlorine-ions might be expected for natural diluted sea-waters. Obviously, variations in the chloride to total salt ratio are due to factors other than those of simple dilution. Factors such as the suspended and colloidal materials carried by streams and the presence of organisms, no doubt, play their part in causing variations in the proportions of dissolved salts.

Buffalo Museum of Science,
Buffalo, New York

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AMERICAN GEOPHYSICAL UNION

Twelfth Annual Meeting

REPORTS AND PAPERS

S E C T I O N O F V O L C A N O L O G Y

Washington, D. C.
April 30, 1931

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SOLUBILITY OF WATER IN GRANITE MAGMAS

Roy W. Goranson

(Abstract)

Geologists have been deeply concerned with the volatile constituents of magmas, for these constituents play important roles in volcanology, in ore-deposition, and in other igneous phenomena. Of these volatile constituents water is the most abundant. In this paper data are presented on the solubility of water in granite glass as a function of pressure from 500 to 4,000 bars (1,000 bars = 1 kilobar = 986.97 atmospheres = 1,019.8 kg per cm^2) at 900° C and as a function of temperature from 600 to 1,200° C at 980 bars.

In this investigation water and granite-glass were sealed up in platinum capsules in order to keep the water in contact with the glass and eliminate carbon dioxide, which was used as the pressure medium, from the system. These charges were brought to the required pressure and temperature in a bomb. The temperature was obtained by means of a platinum-resistance furnace enclosed in the bomb, and pressure, by expansion of carbon dioxide. The runs were from two to four hours' duration, which was found to be sufficient time for attaining equilibrium between the gas-liquid phases. Temperature was then quickly dropped in order to retain the water dissolved in the glass, and since equilibrium in this latter direction was a much slower process, any errors introduced at this point were negligible. The amount of water dissolved in the glass was obtained from the loss in weight on ignition, due care being taken to correct for any losses which might occur while evaporating off the surplus water at 105° C. This granite-glass was obtained by melting Stone Mountain granite, which is a medium-grained normal biotite-bearing muscovite granite.

The solubility of water in this glass at 900° C is 3.75, 5.75, 8.15, 8.90, and 9.35 weight per cent at 0.5, 1, 2, 3, and 4 kilobars, respectively. The solubility of water in this glass at 980 bars decreases by 0.3 per cent per 100° C rise in temperature in the 600-1,200° C temperature range, that is, at 800° C the solubility of water is 6.0 per cent, at 1,200° C it has decreased to 5.4 per cent.

The measured solubility on a natural rock-glass (obsidian), from Mt. Kiamis, Java, of approximately the same composition as Stone Mountain granite gave the same result as was obtained from the Stone Mountain glass. A synthetic glass of composition corresponding to the proportions 75 orthoclase to 25 silica gave a value lower by one per cent than the granite-glass.

It is concluded that natural rhyolite glasses could not very well have more than 10 per cent of H_2O+, and that glasses with from 8 to 10 per cent of H_2O+ should be extremely rare. This is borne out by published analyses made on fresh obsidians.

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THE 1930 ERUPTION OF MERAPI IN MIDDLE JAVA

E. G. Zies

(Abstract)

Merapi has been in the past hundred years one of the most active volcanoes of Java. During this period it has had three outstanding eruptions which have been followed by intervals of somewhat diminished but nearly continuous activity. Domes were extruded during these intervals and were destroyed when the major eruptions took place. The surface of these domes was covered with large blocks of lava. The recent eruption took place during November and December of 1930; it reached its climax on December 19.

The activity for several years prior to this eruption was for the most part confined to the intensely active rumaroles located in the lava-blocks at the top of the dome. There were also occasional extrusions of small lava-flows. Fumarole-temperatures as high as 600° C have been recorded since 1928.

The eruption was preceded for a period of several weeks by local seismic disturbances which were attributed to the avalanching of lava-blocks from the dome. On November 25, glowing lava was noted for the first time; it issued about 300 meters from the top. The lava was extremely viscous, for no definite flow was observed; on the contrary, it built up a dome-shaped mass from which blocks roiled down the steep slopes. This behavior can be interpreted as follows: The first portion of the slowly ascending lava coming into a region of lower pressure lost by diffusion most of its gaseous content; this, in turn, raised the melting-point of the lava to such an extent that it was extruded as a slowly moving viscous mass which quickly chilled and broke up into blocks. It seems quite probable that the steam and gases escaping during the period of intense fumarolic activity that preceded the eruption were derived by diffusion from the slowly rising lava that was elevating the dome. It should also be noted that the chemical activity that was observed on Merapi in 1928 was so intense that the walls of the Volcano must have become greatly weakened, thereby providing a path of egress for the new lava.

On December 18, a black cloud enveloped the peak of the Volcano. On the following day, the breach in the flank was greatly enlarged and permitted a less viscous lava, highly charged with gas, to seemingly boil out of the Volcano. Great amounts of dry clastic material that was derived in part from the new lava deposited in the breach during November and in part from the old lava, flowed down the mountain slopes and filled the valley of Blongkeng. The depth of the fill varied from 10 to 30 meters. The new gas-charged material was now emitted explosively and was accompanied by dust-clouds that were hot and were observed to glow at night. These glowing clouds came down with considerable velocity and were scarcely interrupted by irregularities in the terrain.

The flows of hot clastic material were intermittent in character; many lives were lost on account of the fact that the natives thought that the eruption had spent its force after the first flow and returned to their homes. They were killed during the subsequent flows. The glowing clouds also caused many deaths. Their speed, however, was so great and they persisted for such brief intervals of time that natives who had sought refuge within their homes were spared.

This eruption of Merapi quite forcefully compels us to focus our attention on one of the fundamental problems of volcanism, namely, the effects, at elevated temperatures and pressures, of water and gases on lavas (especially andesites and rhyolites) and the behavior of such lavas when they are forced into a region of lower temperatures and pressures.

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VOLCANOES OF KATMAI DISTRICT IN 1930

R. F. Griggs
(George Washington University, Washington, D. C.)

This communication was presented informally, and no abstract or manuscript was prepared.

THE TERTIARY VOLCANO AT CRIPPLE CREEK, COLORADO

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This communication was presented informally and no abstract or manuscript was prepared.

THE VALLES MOUNTAIN VOLCANIC CENTER OF NEW MEXICO

Clarence S. Ross

(Abstract)

The Valles Mountain region lies in northern New Mexico about 30 miles west of Santa Fe, 50 miles north of Albuquerque, and just west of the Rio Grande. The elevation varies from 6,500 feet at the Rio Grande to 1,200 feet on the higher peaks.

The oldest rocks of the area are pre-Cambrian granites, which form the core of the Nacimiento Plateau and San Pedro Mountain to the west of the Valles Mountains. The very irregular surface of the pre-Cambrian is overlain by Pennsylvanian and Permian beds and these by the Santa Fe formation whose different parts vary greatly in Geologic Age.

The oldest group of volcanics is dominantly andesite and latite but contains basalts and rhyolites. Much of this material is chaotic flows, but the basalts and some of the andesites are even-bedded flows, and locally there are great thicknesses of volcanic breccia. The high peaks reaching 12,000 feet are the erosion remnants of this group of volcanics. Associated with this is a group of diorite intrusives in the Bland area. These are highly altered and great masses are completely silicified. With this was some mineralization at Bland, which was at one time a gold camp. The age of this group of volcanics is not directly determinable but they may be the equivalent of Miocene volcanics of Colorado.

The exact center of these eruptions is not evident, but it must have been in the immediate region and probably was not far from the later center of eruption. After a period of profound erosion, there occurred a series of basaltic eruptions. These were all from local centers and in a number of them the craters are well preserved. Flows extended for several miles and a number of mesas in the northern and southern parts of the region were basalt capped, and the basalt-area extending from the Rio Grande almost to Santa Fe also belongs to this group.

After an interval during which there was little erosion, occurred the period of explosive rhyolitic eruptions on a stupendous scale. A great crater was blasted out of the older andesite-latite volcanics. This was 16 to 18 miles in diameter, over 50 miles in circumference, and 600 to 800 feet deep. The materials ejected were almost exclusively tuffs, which were deposited in even beds sloping from an elevation of about 9,000 feet at the crater-rim to about 6,000 feet at 12 to 14 miles to the east at the Rio Grande. This is much the largest crater known, being even larger than the great Ngorongoro crater of Africa.

This crater is not a caldera for there was no subsidence. Red beds are exposed within the crater at the same elevation as outside the rim. The occurrence of these beds and of masses of the older latite within the crater shows that the explosive vent through which the volcanic debris was ejected was much smaller than the present extent of the crater floor. Possibly there were several vents.

The debris ejected was almost exclusively tuffs but flows did extend for a short distance beyond the rim. This shows that lava did rise to fill the crater, but it must have soon sunk back. The tuff-beds that form the flanks of the crater are best developed on the east where they form the Pagareta Plateau, which is cut into long narrow mesas by radiating canyons that reach 1,000 feet in depth. Some that deep are entirely in tuffs, but others are cut partly in the underlying older volcanics, and

and some into the Santa Fe. On the south and southwest the Paleozoics are penetrated and the granites exposed. It is not possible to make even a rough estimate of the quantity of material ejected from this crater because the amount that fell outside the area can not be determined but the total amount must have been immense.

The tuffs form uniformly sloping beds and in some sections a dozen beds are exposed that differ in texture and color but little in composition.

At the close of the explosive period there must have been this great crater 16 to 18 miles in diameter and perhaps in places somewhat deeper than at present. There was one area several square miles in extent and reaching a height of about 1,000 feet that was made up of older volcanics that had not been entirely blasted out of the crater.

After a period of some erosion a new era of volcanic activity built up secondary cones within the great crater and a few small ones on its northern flanks. The greatest of these secondary cones is 3,000 feet high but several others are 2,000 feet or more. Most of these are rhyolitic but a few are andesitic. The materials are largely crystalline, but very large amounts of obsidian and pumice were formed.

The great crater is now drained by two streams that have breached the rim but within the crater there has been little erosion and the streams meander over the crater floor. At one time the outlets were so high that the crater was a great lake with the peaks of the secondary cones rising above its waters. They persisted long enough for wave-cut terraces to form on the flanks of many of these peaks.

There is no way of definitely dating the time of the later eruptions that formed the great crater and the secondary cones. It was comparatively recent, however, and may have been as late as early Pleistocene.

An area within the crater is marked by numerous hot mineralized springs. A large spring of hot, but pure water issues from the base of the volcanics and it seems that this is merely meteoric water that has been heated by contact with volcanic rocks that retain some of their original heat.

U. S. Geological Survey,
Washington, D. C.

AMERICAN GEOPHYSICAL UNION

Twelfth Annual Meeting

REPORTS AND PAPERS

SECTION OF HYDROLOGY

Washington, D. C.
May 1, 1931

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THE INCEPTION AND DEVELOPMENT OF THE INTERNATIONAL SECTION OF HYDROLOGY

G. W. Littlehales

(Abstract)

The avenue to the inception of the International Section of Hydrology was opened by the Constitutive Assembly which met in Brussels in 1919 to establish the International Research Council and its membership of Unions. In the Constitution of the Union of Geodesy and Geophysics, then ordained, provision was made for extending the register of sections which were initially instituted, and, accordingly, it was in regular course that the Italian delegation to the general assembly of the International Union of Geodesy and Geophysics at Rome in 1922 introduced a measure for the establishment of a Section of Continental Hydrography. It fell to my lot to be appointed by the President of the Assembly to serve as a member of the Committee formed to consider this measure, which was eventually recommended to the favorable consideration of the assembly with the amendment that the name of the proposed organization should be the International Section of Scientific Hydrology. At its inception, thus brought about by the action of the general assembly at Rome, one of the primary motives appears to have been to make the new Section a means of reconstituting the former International Association of Glacialists, which had ceased to function during the years of political disturbance in Europe. At the first meeting of the International Section of Scientific Hydrology, which was held at Madrid in 1924 in connection with the general assembly of the International Union of Geodesy and Geophysics, a Commission on Glaciers was formed and provisions made for compiling and publishing the Report on Glaciers for the period elapsed since 1914. A Commission on Statistics was also appointed with a view of bringing about uniformity in the publication of the materials of hydrology and for laying the foundation for mutual understanding among national services in the conventional signs and symbols employed in hydrological maps and in the definitions of the terms found in the literature of this science. Furthermore, plans were laid for the compilation of a comprehensive report on the actual state of hydrology in the member-countries of the Section, and the ascertainment of an inventory of their hydrological resources.

The general assembly of the International Union of Geodesy and Geophysics at Prague in 1927 proved to be an important occasion for the International Section of Scientific Hydrology, resulting in accessions to its ranks and more general realization of its scope and potentialities. It was on this occasion that Dr. Martel of the French National Section of Hydrology presented a comprehensive memoir entitled "Les Eaux Souterraines," in which the contributions of Meinzer are favorably noticed; and the learned Dr. Smetana of Czechoslovakia gave a summary of the reports sent in on the state of hydrology in all the countries belonging to the International Section of Scientific Hydrology. On account of their general usefulness, a copy of each of these two reports is presented today for deposit in the archives of the Secretary of this Section.

And a third report is brought to show the nature of those that were communicated to the meeting last year at Stockholm, where the principle of national reports was yet further advanced and furnished striking evidence to show that harmonious cooperation breeds plenty and that advantages increase by being shared. In this report by the French National Committee, there is a second memoir by Martel upon subterranean waters, besides an essay by Wilhelm on the theory of the entrainment of heavy materials in rivers of rapid current, and two mathematical memoirs by Coutagne treating of the discharge of flood-waters and of river-hydraulics.

U. S. Hydrographic Office,
Washington, D. C.

THE FIELD, SCOPE, AND STATUS OF THE SCIENCE OF HYDROLOGY

Robert E. Horton

Introduction--In some of its aspects hydrology is as old as its foster parents--geography and meteorology. Among the earliest engineering operations of record is

the construction of wells, frequently described in the Book of Genesis--an example of applied hydrology. (Some wells of extremely ancient and probably pre-historic construction are still existent and in service in Arabia. They are fully described in Thomas Ewbank's "Hydraulics and Mechanics," New York, 1870.) As in the case of geography and meteorology, so also hydrology has been mainly qualitative in character until recently. Only with the beginning of its quantitative development could it be considered that hydrology definitely emerged from the other Earth-sciences.

There is a simple basic fact involved in the hydrologic cycle

Rainfall = Evaporation + Runoff

(Inasmuch as most persons think of evaporation in a more restricted sense, it is better to define runoff as equal to rainfall minus water-losses. Water-losses are of three kinds, all evaporative in their nature: (a) Interception; (b) transpiration; (c) direct evaporation from soils and water-surfaces.) Quantitative proof of this law could only come after quantitative determinations of rainfall, evaporation, and runoff had been made.

The belief was not uncommon as late as the 18th century that rivers derived their waters, even in floods, from the interior of the Earth and not from rainfall and snow. The fact that streams continued to flow for long periods in the absence of rain may be considered to have lent support to this belief. The history of this idea and the great length to which it was disputed pro and con by eminent authorities is described by Keilhack (ref. 1, list at end of paper). The "Treatise on Rivers and Torrents" by Paul Frisi (ref. 2), first published at Lucca in 1762, set the matter at rest, Frisi having followed various rivers to their sources and observed to his own satisfaction that they derived their waters from surface-runoff from rainfall and from springs and seepage, also derived from rainfall.

Hydrology, perhaps because it is a new science, can be defined in a manner that is more specific and less impressionistic than some of its older sisters in the domain of knowledge. Even here, as in the case of most other sciences, it is difficult to devise an investiture which will include all essential features of the subject and omit none.

As a pure science, hydrology deals with the natural occurrence, distribution, and circulation of water on, in, and over the surface of the Earth.

Defining science as correlated knowledge, it is true that a statement of the field, scope, and status of hydrology at the present time may be little more than a birth-certificate. Nevertheless, there is scattered through scientific and engineering literature a mass of quantitative results adequate to make a most respectable body of science, wanting only to be coordinated. The harvest truly is plenteous but the laborers are few.

The word hydrology has sometimes been misapplied as if limited to the phenomena and circulation of underground-water, although the broader meaning of the term was recognized, as is shown by the date of publication of what was probably the first English book on the subject--Beardmore's Hydrology, London, 1862 (ref. 3). Even at the beginning of the present century many persons, including some engineers and geologists, considered the term hydrology as applying only to underground-water phenomena. This restricted use has been carried down nearly to the present date in Germany by the publication in 1923 of a Handbook of Hydrology, an excellent work by E. Prinz, but devoted exclusively to underground-water (ref. 4).

In one sense the field of hydrology is the Earth and so is co-terminous with other geo-sciences. More specifically the field of hydrology, treated as a pure science, is to trace out and account for the phenomena of the hydrologic cycle.

"Natural waters" have come to mean those which are pursuing their natural course of circulation, and hydrology is not concerned with waters which have been temporarily removed from such circulation while so detained and used, as, for example, waters impounded and distributed for potable use or waters utilized in industrial processes or waters of crystallization or hydration in nature.

Imbeaux (ref. 5) classifies hydrology as the "branche fort importante de la Physique du Globe--est une science tres vaste--aussi vasteque la répartition de l'eau dans l'univers est elle-meme étendue." At least it may be said that among the Earth-sciences hydrology is basic, in the same sense as its next of kin--geology and meteorology.

I have used the term field to describe the domain of hydrology as a pure science. The word scope may be used to describe the manner in which and the extent to which it covers this domain. The scope involves all those portions of the sciences and arts in which hydrology, pure and applied, plays a significant role. Both the scope and problems of hydrology are closely related to the various branches of applied hydrology. This is natural since it is mainly in the applications that new problems arise and the scope of the science is extended. This is especially true where other sciences involve problems that require the aid of hydrology for their solution.

The definitions given clearly indicate the field covered by hydrology as a pure science. Its scope is limited to considerably less than the entire field of water-science.

Hydrography is concerned with the natural distribution of water-resources and so may be considered as a branch of hydrology. Hydrography includes both areal and volumetric determinations of the extent of water-resources, is purely quantitative and may therefore be considered more properly as a branch of surveying. Hydrology does not include certain sciences which center around water as a physical medium, such as the biology of water and many aspects of oceanography.

The fact that hydrology has developed largely within the fields of other sciences has led to the peculiar situation that it has reached a state of great economic importance without either a society or English periodical devoted uniquely to its advancement. The Zeitschrift für Gewässerkunde, the publication of which began in 1898 and terminated during the World War, was excellent and representative of all fields of hydrology and it is unfortunate that it could not have been continued (The Hydrological Review, published in Russia beginning in 1915, is not generally available to English readers). This periodical contained in its earlier issues a series of papers by Ed. Imbeaux entitled "Essai-programme d'hydrologie" (ref. 5). These were intended to set forth in outline the principal lines of development which have taken place in hydrologic science down to 1898. The scope of hydrology at that time, as indicated by these articles, was far less extensive than at present. In the period from 1862 to the beginning of the present century the only book in English bearing the specific title "Hydrology" was that of Beardmore (ref. 3), a mixture of hydrology and hydraulics. The pioneer book on the science of hydrology in the modern sense is the volume on this subject by J. F. Bubendey, first published in 1876 as the first volume of the section on water-engineering of the German "Handbook of engineering science" (ref. 11). This book, revised, still continues as the standard European treatise on this subject. The most recent and apparently the only work devoted exclusively to hydrology in continental Europe is the volume on "Rivers" by Gravelius (ref. 6), published in 1914, which comprised the first of four volumes of a contemplated work, never completed, on the elements of general hydrology.

The literature of hydrology is, however, extensive and comprehensive. It appears mainly under other captions and in relation to special topics. It is largely distributed through the literature of meteorology, engineering, agriculture, botany, forestry, ecology, geology and geography, hydraulics, and, to some extent, other sciences.

Engineering literature, particularly the transactions of the national and other American and foreign engineering societies contains a large amount of valuable hydrologic material, in much of which the attainment of quantitative results has been undertaken.

The development of hydrology, owing to lack of centralization and lack of coordination, has been extremely unbalanced. Some of the topics have received extensive treatment, as, for example, transpiration, the theory of ground-water flow, and the phenomenon of rain-intensity for short intervals, while other topics often closely related and equally important have been much neglected, such as infiltration, rainfall-duration, and rain-intensity for longer time-intervals.

Relation of hydrology to conservation--Emphasizing the economic aspects, hydrology may be described as being concerned with the occurrence, utilization, and conservation of natural water-resources, the word conservation being here used to include not only constructive uses, involving the substitution of beneficial for passive conditions, but as involving also the prevention of injurious or destructive activities by natural waters, as in soil-erosion and damaging floods.

In accordance with the old Roman law "Aqua currit et debet currere ut currere solebat"--water may be used as it flows and only as it flows. This applies physically as well as legally to unregulated waters in circulation. Conservation of water-resources, therefore, necessarily implies utilization; non-use is waste.

There are two degrees of conservation of water: (1) Use as it flows in nature; and (2) increased use and efficiency of use by regulation--in other words, conservation by storage of flood-waters, as implied in Kipling's lines: "They shall gather the floods as in a cup and pour them again at a City's drouth."

The hydrologic cycle

Again, hydrology may be regarded as charged with the duty of tracing and explaining the processes and phenomena of the hydrologic cycle, or the course of natural circulation of water in, on, and over the Earth's surface. This definition has the advantage that it clearly outlines the field of hydrologic science.

The hydrologic cycle is familiar to all in its general aspects--its complexity is less commonly appreciated.

The hydrologic cycle is often considered as consisting of three phases, namely, rainfall, runoff, evaporation. It may more properly be considered as consisting of two main divisions, each in turn involving two principal phases: (1) Atmospheric division--vapor-phase and rainfall-phase; (2) surface-division--runoff-phase and evaporation-phase. It is interesting to note that each division comprises: (1) Transport of water; (2) temporary storage; and (3) change of state. Thus the atmospheric division comprises (a) vapor-flow, (b) vapor-storage in the atmosphere, and (c) condensation or change from vapor to liquid or solid state. The surface-division comprises (a) runoff, infiltration, or ground-water flow, (b) surface, ground-water, and soil-moisture storage, and (c) evaporation, or change from solid or liquid to the vapor state. (Evaporation occurs slightly in the atmospheric division and condensation occurs to some extent in the surface-division; freezing and melting occur in both divisions.)

Any natural exposed surface may be considered as a unit area on which the hydrologic cycle operates. This includes, for example, an isolated tree, even a single leaf or twig of a growing plant, the roof of a building, the drainage-basin of a river-system or any of its tributaries, an undrained glacial depression, a swamp, a glacier, a polar ice-cap, a group of sand-dunes, a desert playa, a lake, an ocean, or the Earth as a whole.

Figure 1 is intended to show the principal steps involved in the hydrologic cycle in the most typical case, that of a drainage-basin tributary to the ocean.

Beginning at the top and reading counter clock-wise the path of the water in the course through the hydrologic cycle may readily be traced. Figure 1 is, however, little more than a suggestive picture from which a wealth of detail is necessarily omitted. For example, on the diagram but little space is devoted to evaporation from the soil. This, however, is a very complex process. It involves the flow of vapor from the air into the soil, from the soil into the air, temperature-differences between the soil and air, the diurnal and annual heat-waves flowing into the soil, evaporation from the water-table, and also evaporation from capillary films in the non-saturated zone. Vapor evaporated in one part of the soil may flow to and be condensed in another. These phenomena involve the effect of both salts in solution and of the radii of capillary films on the vapor-tension of equilibrium. As a further illustration, the little segment labeled "Temporarily stored on the surface" includes water some of which goes into the soil as infiltration. In that case the detention or storage is often but a surface-film or thin layers in tiny pools. Temporary surface-storage

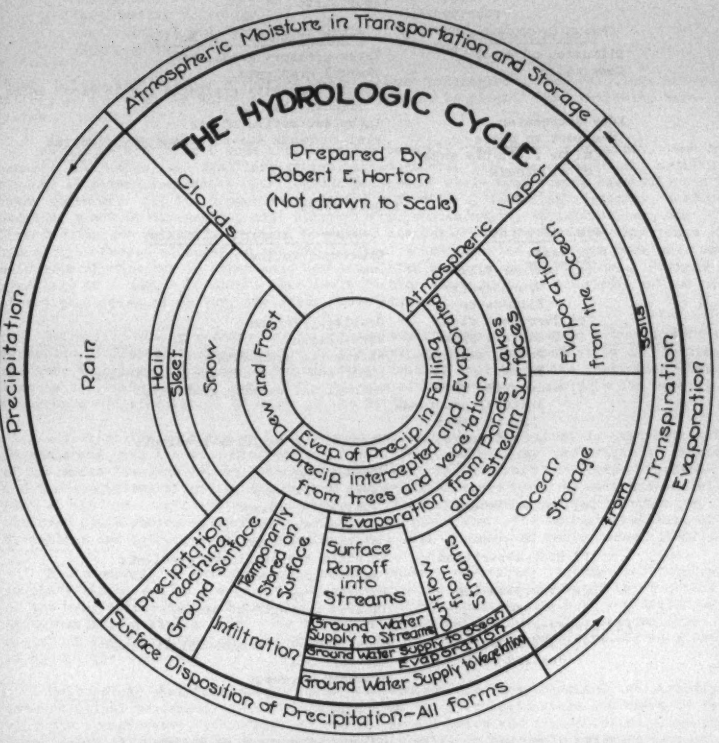

Fig. 1--The hydrologic cycle

ranges from such transitional phenomena to the extended and long-continued storage of water in lakes, swamps, marshes, as accumulated snow-layers in winter, as glaciers and polar ice-caps. Other details might be similarly amplified.

Modes of motion in the hydrologic cycle--The operation of the hydrologic cycle depends on motion--the transfer or transportation of water in each of its principal states, solid, liquid, and vapor. The methods by which this translationtakes place are so various and so important to the accompanying phenomena that--no one else having done so--it may not be amiss to enumerate some of them here.

Vapor state

Kind of motion	Cause of control of motion
Diffusion of vapor	Vapor-pressure gradients
Convection	Thermal gradients
	Specific-gravity gradients due to vapor being lighter than air
Eddy-convection	Turbulent motion of air
Transport en masse	Wind-currents due to barometric gradient
(a) As invisible vapor	
(b) As clouds	

Liquid state

Kind of motion	Cause of control of motion
(1) En masse	Gravity-friction
(a) Laminar flow	
Ground-water	
Film-water	
(b) Turbulent flow	Gravity-friction
(c) Transient flow	Wind-action
Waves, seiches	Barometric gradients
Tides	Lunar and solar attraction-friction
(d) Convective flow	Thermal and density gradients
Seasonal overturning of lakes	
Oceanic circulation	Thermal and salinity-gradients
	Wind-action
	Earth s rotation
(e) Soil-moisture	Capillary gradient
	Surface-tension
	Solution-gradient
(f) Root-absorbtion	Solution and capillary gradients
	Osmotic pressure
(g) Transpiration-stream	Solar energy
	Tensile strength of water
(2) Disperse	
Rain-drops	Gravity-air friction--Stokes law
Fog and mist	Air-currents
	Brownian movement

Solid state

Kind of motion	Cause of control of motion
(1) En masse	
Glacier-motion	Gravity-plasticity
Avalanches	Gravity
Ice-transportation	
River ice, icebergs	Ocean-currents
	Wind-action
(2) Disperse	
Hail and sleet	Gravity-air friction
Snow	
Falling	Gravity-air friction
Drifting	Wind-currents

Relation of hydrology to other sciences

Hydrology is in a large measure founded on physics and hydraulics. It has a number of branches which are commonly recognized. A list of these branches indicates both the principal lines of application of hydrology and its most intimate relationships to other sciences. They include, among others:

Meteorological hydrology	Soil-physics
Engineering hydrology	Oceanography
Agricultural and forest-hydrology	Geography and physiography
Hydro-geology	Glaciology

These in turn intermesh in a complex manner. Some indication of the relations of hydrology to a few of the more basic of these sciences is given in the following paragraphs.

Physics--Throughhabit some processes are commonly thought of as physical, such as osmosis, diffusion, and capillary action, while others, like evaporation, are usually classed as meteorological or hydrological because of their most common association with these sciences. All the processes named and many others, including viscosity, surface-tension, gradient-convection, eddy-convectivity, condensation, solidification, and liquefaction are primarily physical processes and yet are of fundamental importance in hydrology. Recent advances in sub-atomic physics have diverted attention from mass and molecular physics but in other ways have stimulated research in these lines. Advance in hydrology at a number of points must await further advance in our knowledge of the ordinary properties of matter, including those listed.

Hydraulics--Owing perhaps to the earlier application of the name hydraulics to the mechanics of fluids, including water as the most important representative of the class, the term hydrology, in spite of the breadth of meaning implied by its derivation, has come to be limited to that part of the science of water which deals with the natural occurrence and circulation of water on the Earth.

A distinction that may be made between hydraulics and hydrology is that hydraulics is concerned with the mechanics and physics of fluid motion, and the origin or source of the water involved is, in general, immaterial. In hydrology the forces involved and the conditions of motion are natural and are intimately bound up with the activities of the hydrologic cycle. Hydraulics overlaps with and is applied in hydrology wherever fluid motion is involved in the hydrologic cycle. The intimate relation of hydraulics and hydrology is illustrated by the list of modes of motion above given.

The phenomena of wave-motion in natural waters--oceans and streams--has developed in the field of and is properly a part of hydraulics but flood-movement in rivers is of the very quintessence of hydrology. It involves, however, the most recondite phase of hydraulics--variable flow. The theory of ground-water flow, although equally a branch of the hydraulics of non-turbulent flow of fluids, is mainly treated as a branch of hydrologic science.

Meteorology--Rainfall, evaporation, and atmospheric vapor-movement are strictly meteorological processes. Take these away from the hydrologic cycle and there is left only the runoff-phase, including, of course, ground-water and soil-moisture phenomena. Practically all vegetation is dependent on soil moisture, that is, moisture derived from infiltration of rainfall. Streams are related to human affairs, providing waterways for navigation, water for irrigation, power and mining uses, and for potable uses, as well as serving for sewage-dilution and natural purification and disposal of waste materials. It follows that the economic applications of hydrology are derived almost wholly from the surface- and underground-waters. The supply available for infiltration and runoff is derived from rainfall, on the one hand, and is limited by evaporative processes, on the other. The economic importance of infiltration and runoff is so great that the need for the consideration of the phenomena of rainfall and evaporation separately from meteorology in relation to the hydrologic cycle is imperative.

Engineering hydrology--This includes the application of hydrologic data and theory to the runoff-problem in all its many ramifications, both surficial and underground, and including all its phases--floods, normal flows, and minimum flow--together with its economic applications, such as stream-regulation by storage and the provision of water for power, navigation, domestic, and industrial purposes.

The application of hydrology in some engineering fields, as, for example, in land-drainage and irrigation, may equally well be classed as part of agricultural hydrology. The objective of engineering hydrology is the application of hydrology to

problems of utilization and conservation. This necessitates the use of quantitative results. Engineering applications have until recently provided the main incentive for these lines of research by which the scattered qualitative incunabula of hydrology may be transformed into coordinated science. Much remains to be done to bring hydrology fully into the domain of quantitative science, as will be more fully noted later. For example, in a large measure the existing mass of detailed knowledge--not yet altogether coordinated--of rain-intensity, has developed not from investigations made primarily for meteorological reasons but largely because of the importance of a knowledge of rain-intensity in the practical problem of the sewerage of cities and towns.

Agriculture, forestry, and the botanical sciences--As already noted, virtually all plant-life is dependent on infiltration. Two evaporative processes noted in the hydrologic cycle, interception and transpiration, are directly related to plant-life.

The supply of moisture to plant-roots, its conduction through the plant to the living cells and thence to the evaporating surfaces within the stomatal cavities are vegetational processes. Thus certain branches of botany, particularly plant-physiology and ecology, are profoundly interwoven with hydrology. The water-relations of plants are of great importance and neither the underground or hydrologic factors nor the aerial or meteorological factors involved can be adequately considered separately from the other factors.

The plant lives in a dual environment, the underground portion in an environment of soil, soil-moisture, or soil-solution, water-vapor and soil-air, coupled with temperature-phenomena, related to but differing greatly in detail from those of the overlying air. The aerial portion of the plant lives in an environment involving the air itself, water-vapor, light--particularly sunshine--the alternation of light and darkness, and temperature as conditioned by insolation and radiation and by atmospheric circulation. Growth and life of the plant depend on the maintenance of a suitable balance between the physical effects on the plant of the various factors in operation in the two environments. A typical illustration is that afforded by the phenomena of wilting of plants.

Similar examples could be given of the relation of hydrology to practical agriculture, as in the soil-erosion problem, irrigation, and land-reclamation by drainage. The relations of hydrology to forests, to natural vegetation on uplands and in swamps and marshes differs only in degree and detail from its relation to crop-plants. The hydrology of transpiration and water requirements of plants has developed along two lines, (1)--and primarily--as a part of the science of plant physiology and (2) as a part of agricultural engineering. Whether all those aspects of hydrology which relate to plant-development should best be classified as agricultural, botanical, or ecological hydrology is a question which may be left for workers in these fields to determine.

The basic data of hydrology

These consist for the most part of direct observational data relating to precipitation in its various forms, the volume of flow of streams, evaporation or water-losses of the various kinds, data of ground-water fluctuations and flow, and data of soil-moisture conditions. Each of the main processes of the hydrologic cycle can occur in a variety of ways, involves various elements, and requires a great diversity of kinds of observation to cover the subject completely.

Here, only a brief mention will be made of the status of the collection of data of the three main phases, namely, rainfall, water-losses, and runoff, with some comments on ground-water. These brief notes are all intended to be suggestive rather than inclusive.

Rainfall--Quantitative records of rainfall appear to have been kept in India in the fourth century B.C. The earliest records of rainfall now in existence are meager, undated averages for Palestine during the first century of our era. The modern type of rain-gage is known to have been in use in the days of Leonardo da Vinci, 1452-1519. Although the invention of the rain-gage is often attributed to Castella, 1639, and to Sir Christopher Wren, 1663, it is certain that rain-gages were in use in Korea as early as 1442 (ref. 7).

There is an average of one rain-gage or more to every 40 square miles in Jamaica, Barbados, St. Kitts, Great Britain and Ireland, Denmark, Saxony and the Straits Settlements, Victoria and Mauritius. In the more thickly settled portions of the United States there is usually one United States Weather Bureau station in each county or one about every 500 square miles. In New England there are in addition many private rainfall-records. In the sparsely settled regions in western United States there is, however, on the average only one rain-gage in an area of several thousand square miles (ref. 7).

Even where the most complete and extended stream-gaging data are available it is nearly always necessary in the practical application of the data to extend the records in time or to apply them at some other location, or both. For both these purposes rainfall-data and physiographic data may be either the only available guides or valuable as auxiliary information. In the United States, rainfall-records are often not sufficiently numerous or complete to serve satisfactorily nor are the existing records generally checked by systematic inspection (ref. 8). It is certain that a large majority of existing winter records of precipitation are deficient because of the common failure of the ordinary rain-gage to catch the full amount of snow which falls, especially in the presence of wind (ref. 7). The adoption of better methods of measuring snowfall than those generally in use is greatly to be desired.

There are many lines of additional meteorological data needed in connection with hydrological work (ref. 14). Most of the data could readily be obtained by existing Weather Bureau and other organizations.

Stream-flow--Apparently the earliest continuous American records of stream-flow for any appreciable time-interval were those made by the pioneer American engineer, John B. Jarvis, on Madison Brook, for the calendar year 1835, and on Eaton Brook, June to December 1835 (ref. 15). Both streams are head-water tributaries of Chenango River in New York. The next important records were those of the Sudbury and Cochituate areas of the Boston water-supply and of the Croton area. Gradually records were established at other locations, including the Hudson River at Mechanicville, 1887, but records were extremely meager prior to the beginning of the present century, at which time systematic stream-gaging had been extended generally over the United States under the direction of Charles D. Walcott and Frederick H. Newell.

Records of stream-stages go back to earlier periods and some of these early records have later been converted into discharge-records. Notable among the early stream-stage records is the record of flood stages of the Nile, extending back to the seventh century (ref. 9) and long records of stages of European rivers collected by Gustav Ritter von Wex (ref. 10). A few important runoff-records in Europe began about 1850. At the present time systematic stream-gaging is carried on generally in the United States and Canada, to a limited extent in England and continental Europe, and sporadically or not at all elsewhere. Taken the world over, the greater part of the economic development of water-resources thus far carried out has been made without the aid of actual measured runoff-data. The future economic development of Asia, Africa, and South America depends largely on utilization of water-resources and the extension of systematic stream-gaging to a world-wide basis is greatly to be desired.

It happens that in general it is more difficult to obtain continuous and accurate records of extreme stream-flows, that is, flood-crests and minimum flows, than of the flow for intermediate conditions but it also happens that the discharge during floods and in low-water periods is of the greatest practical importance. It is therefore desirable that methods of stream-measurement be extended and improved to increase the continuity and accuracy of the records and to secure fuller detail in periods of flood and minimum flow.

Water-losses

Evaporation--The late J. G. Symons remarked that evaporation was the most desperate branch of the most desperate science of meteorology. There are many hundreds of evaporation-records which have been kept throughout the different countries of the world, representing thousands of years of observations, yet the methods used in measuring evaporation are almost as diverse as the records are numerous. One of the outstanding problems of evaporation is to devise means by which more of these records

can be reduced to a basis of comparison. This also suggests the desirability of the general adoption of standard methods of measuring evaporation, one similar perhaps to that adopted by the United States Weather Bureau for its class A stations. It appears, however, that two, and perhaps more than two, standard methods of measuring evaporation are needed--one to serve the purpose of engineering hydrology, another to meet the requirements of micro-climatic conditions involved in plant ecology and in the study of the relation of transpiration to evaporation.

Direct observational data in relation to evaporation from natural soil-surfaces on bare or cropped fields and in forests are extremely meager except as derived from lysimeter experiments. As a rule no provision is made for surface-runoff from lysimeters and the results as regards evaporation from the soil-surface correspond more nearly to that which would take place from a rainfall-amount equal to the actual rainfall plus the runoff which would have occurred if permitted, rather than to the soil-surface evaporation from the actual rainfall.

Interception--The existing data of rainfall-interception by vegetation need extension in a variety of ways, particularly for winter conditions. The interception of snow may vary from a trifling amount for very dry snow falling at sub-freezing temperatures in the wind, to a high percentage of the precipitation for moist snow with the air-temperature around 32°. The existing data of snow-interception are mostly European and show surprisingly large losses of precipitation from this cause, perhaps due to prevalence of moist, sticky snow in the regions where the observations have been taken (ref. 16).

Transpiration--Data of transpiration-losses from plants are extensive and include: (1) Botanical laboratory-experiments, giving mostly relative rather than quantitative results; (2) Results of field laboratory-experiments, such as those of Briggs and Shantz in this country, J. W. Leather in India, and a number of others--unfortunately in connection with many such series of experiments the records of the correlated meteorological factors are incomplete; (3) field-experiments, such as those which have been carried out in connection with irrigation-agriculture in western United States and Canada--until the relation of transpiration-losses to evaporation and other factors is better determined it is difficult to apply quantitative data of transpiration-losses obtained in one locality to conditions for the same variety of plant or vegetation in another locality.

With regard to transpiration-losses from forests, the experimental results by Höhnel, in Austria, 1878-1880, although unsatisfactory are still the best available (refs. 12, 13). Even with complete data of unit transpiration-requirement--say per pound of dry-leaf matter produced by a forest--it would still in general be impossible to estimate accurately the transpiration-losses from forests in individual seasons because of the almost complete lack of data of the extent of the leaf-crop of forest trees. Data of leaf-crops from forests could and should be obtained. There are practicable methods of obtaining such data (ref. 13).

Phenology--The extension of the phenological records is greatly to be desired. In the United States, phenological data should be collected in accordance with some definite system by the Agricultural Experiment Stations and other organizations and the results incorporated in annual reports similar to those of the Committee on Phenology of the Royal Meteorological Society. Crop-yield data similar to those published in the Yearbook of the United States Department of Agriculture but extended to cover individual counties for the principal crops should also be regularly collected and published. Such data would furnish: (a) A basis for the economically important correlation of crop-yield with weather and hydrologic factors; (b) a basis for the equally important economic problem of crop-yield prediction; (c) a basis for practical application of transpiration-data in connection with the solution of the runoff-problem.

Ground-water and soil-moisture--Aside from the direct economic importance both of underground-water and of soil-moisture, these are both factors of great importance in relation to runoff. The flow of streams during most of the time when rain is not falling is maintained solely by storage, and in the absence of surface-storage it is maintained by ground-water flow alone. There is little direct relation between stream-flow and rainfall during periods of minimum and ordinary flow. In any attempt to correlate runoff with its controlling factors, two important links in the chain of data

are usually wanting: (a) The change of ground-water level during the period under consideration, and (b) the change of soil-moisture storage in the capillary or non-saturated zone above the water-table.

There are but few instance, such, for example, as the Pomperaug area in Connecticut (ref. 17) and certain chalk areas in England (ref. 18) where comprehensive researches on the relation of ground-water to stream-flow have been made. It appears that with extensive ground-water storage there is a very definite relationship between ground-water level and stream-flow in the absence of rain, whereas in certain other classes of areas, owing either to lack of a permanent ground-water table or to complicated ground-water conditions, there may be but little relationship between ground-water level and stream-flow. Areas where the relationship exists are, however, of wide extent and owing to the existence, in general, of a considerable lag between ground-water replenishment and the resulting effect on streams, records of ground-water level may afford a valuable basis of stream-flow prediction.

Ground-water level records and records of soil-moisture should be maintained much more extensively than at present, both because of their direct economic value and because of the need of such data as a basis for scientific researches in hydrology, particularly with reference to the solution of the runoff-problem.

A system of ground-water level records was maintained by Dr. H. B. Baker at a number of locations in the state of Michigan for a number of years beginning about 1880. Owing to the presence of deep glacial drift-deposits and consequent extensive ground-water storage, these records show a fair correlation between ground-water level and stream-flow and even between ground-water level in the interior of Michigan and the levels of the Great Lakes. There is no reason why similar continuous records of ground-water level should not be maintained by suitable state or government organizations generally throughout the country. They should be accompanied by records showing the amount of soil-moisture storage remaining in the ground, say, at the end of each month.

The problems of hydrology

A complete list of the problems of hydrology is impossible. It would be nearly co-terminous with a list of the applications of hydrology in both pure and applied science and in addition would involve much that is fundamental to the science itself. (Nevertheless, a list of the more important problems of the present time is desirable, as a basis for a coordinated program of research. The preparation of such a list has been undertaken in connection with the water-requirements of vegetation--see reference 20.) As in physics and other sciences, an advance toward the solution of one problem uncovers others. The central problem is that of determining the physical processes and principles and the quantitative relations involved in the hydrologic cycle--or less comprehensively, as put by Ed. Imbeaux, the solution of the runoff-problem. This problem serves also as an illustration of the fact that, in general, science can only progress as fast as the necessary quantitative data become available. In the case of the runoff-problem there are, in addition to the lack of ground-water data, as already noted, other lapses of important information.

Many attempts have been made to correlate runoff with rainfall and other factors, principally temperature and evaporation. Even with the best available data an estimate of seasonal runoff, year in and year out, if based on these factors alone, is likely to be considerably in error. All existing formulas become still more unreliable when applied to a single day or to the fortuitous rainfall and still more casual runoff of arid regions. Ultimately, runoff equals rainfall minus water-losses and this is the basis of the simple English rule of deducting 12 to 16 inches from the mean rainfall, a rule which is fairly accurate for average runoff for British climatic conditions and with British rainfall-data, but, like other rules, is worthless for short intervals, particularly periods with no rainfall. The failure of existing methods in the case of estimation of runoff for short intervals or storm-periods indicates that there are some important variables not included. Among these may be mentioned rain-intensity and duration and also infiltration-capacity. So far as direct surface-runoff is concerned it has little to do with water-losses (other than interception.) It is governed by rain-intensity in excess of infiltration-capacity and by rainfall-duration.

In spite of the enormous volume of rainfall-data it is difficult to find a drainage-basin where sufficiently complete and detailed information as to actual rainfall-duration and rainfall-intensity is available to permit a close study of the surface runoff-problem from this angle. (Such data are being provided in connection with some of the experimental plats of the soil-erosion program of the United States Department of Agriculture. The first use of the experimental-plat method of studying runoff appears to have been the experiments carried out by Wollny--reference 19--many years ago, using artificial runoff-areas with different slopes, soils, crop-covers, and angles of inclination to the Sun.)

Research requirements

Research in hydrology may be considered as of two kinds: Experimental--field, laboratory; correlative--theoretical and mathematical, statistical and comparative.

Experimental research includes: (a) The collection of basic information under natural conditions, and (b) investigation of specific points by field- or laboratory-methods under controlled conditions. Potometer-studies of transpiration or experimental-plat studies of runoff serve as illustrations of the latter. The object of laboratory-research in general is to furnish a logical framework for the interpretation and application of the basic data.

The results of experimental research do not as a rule become a part of the body of science until they have been correlated to the work of others and coordinated to the general framework of knowledge. This is the object of correlative research. Hydrologic literature is filled with examples of experimental researches carried out on the same subject but done by different workers and under different conditions and which require correlative research for the purpose of harmonizing and classifying the results. Studies of evaporation from pans, already cited, is an example of this class.

It has been suggested that there is less need for the collection of additional meteorological data than for the scientific reduction and assimilation of data already collected. This is true only to a certain extent but applies, as far as it is true, to hydrology. A single example taken from meteorology will suffice to illustrate the manner in which scientific archives have become cloyed with unassimilated observational data in some instances. The amount of literature and data on the subject of air-temperature is enormous. Man lives in an atmospheric environment, mainly within a few feet of the ground-surface. This is also the atmospheric environment of the aerial portions of most plants other than trees. Temperatures of the soil-surface and of the air in the closely adjacent layer are of the greatest importance in hydrology, but with the exception of studies of certain details, such as the occurrence of frost, and the publication of a small German book on the climate of the air-layer close to the Earth's surface, very little has been done to correlate temperature-observations with the temperature of the soil-surface or with the temperature of water-surfaces. Here, as in most other cases where correlative research is undertaken from existing data, it is likely to be found that additional observations of a somewhat different character from those customarily taken are needed to supply connective tissue.

Correlative research includes mathematical research. Advanced mathematical methods have been applied in but few cases in hydrology. These include: (a) Flood-phenomena; (b) ground-water flow; (c) statistical analysis of certain classes of data. There is more geometry in hydrology than might be supposed. The extension of mathematical analysis, both elementary and advanced, to hydrologic problems, should receive more consideration.

Statistical research--Methodology plays an important role in hydrology, particularly applied hydrology. The procedure to be used in the solution of a given problem is nearly always determined by the nature and extent of the data available. The engineer frequently called upon to determine the yield-characteristics of drainage-basins is rarely able to use precisely the same method on different occasions because of differences in the extent and character of the available data. The methods used must suit the data. In the stream-flow problem the available data may range from extended and reliable gagings of the given stream to fragmentary gagings of an adjacent

or remote stream, or no gagings whatever, requiring reliance upon rainfall-data and rules for estimating runoff.

The advance of hydrology depends so much on the matter of methods of reduction and use of data that a brief discussion of this topic seems pertinent here. Three useful rules may be laid down: (1) The method used should be such as to reduce the elements of judgment to a minimum and to their simplest terms--it is easier to estimate linear dimensions than volumes; (2) the method should be one whereby an independent computation from the same data and method would lead as nearly as possible to an identical result; (3) the best possible use should be made of all the available data. The application of the last rule must often be tempered according to the necessities of economy of labor and with due regard to the avoidance of meticulous accuracy.

Owing in part to the large number of independent variables involved in many hydrologic problems, empirical generalizations must often be used. Such generalizations both facilitate the application of the results in practice and their correlation with other similar investigations. The use of empirical generalizations under proper conditions is neither avoidable nor undesirable. It is, however, important to recognize the nature of the physical processes involved and their limitations in connection with the use of statistical methods and empirical formulas.

It may happen that several different types of formulas will give excellent fit to the data within the limits of observation but it is important to use the formula which not only fits the data but which gives rational results for the limiting or boundary conditions. Hydrologic literature contains many empirical generalizations which if extended would lead to absurdities. This is particularly true in the application of unlimited frequency-formulas, such as the Gaussian law of error, to hydrologic data which are subject to finite limitations. (Several frequency-curves have been developed intended to apply specifically to rainfall- and runoff-data. It should be recognized that all frequency-equations are empirical in the sense that their applicability to given data cannot be rigorously proven.) The reasons for these limitations may or may not be obvious. As illustrating instances where finite limitations should be recognized in frequency analysis, it may be noted that while we do not know the exact maximum limitation of rainfall at Washington, yet there are meteorological reasons which show conclusively that it certainly cannot be 1,000 inches in a month. Similarly, Rock Creek cannot produce a Mississippi River flood--any more than a barnyard fowl can lay an ostrich egg, and for very much the same reason, namely, it would transcend nature's capabilities under the circumstances.

Summary

Perhaps history will describe the present era as the second renaissance of science. Many of the older sciences have grown to unwieldly proportions and have multiplied by fission, so that each new science is part of its parent, yet a separate individual.

Hydrology is in the same situation as many other sciences which through rapid growth and sub-division have suffered from lack of coordination of effort and incomplete correlation of results. Science progresses as it has problems to solve and solves them--but also as it develops and classifies the results in relation to the whole body of scientific knowledge.

This paper points out some of the high spots, and also a few of the low spots, in the science of hydrology. Much that is contained herein indicates the weakness and inadequacy of hydrologic science as it stands today. This need discourage no one. Quantitatively, at least, hydrology is little more than a new-born science--many an infant needs a spanking at birth to give it the breath of life. There is, in hydrology, as already noted, (a) a large mass of unassimilated data, (b) a mass of mostly uncoordinated results of research, and (c) a galaxy of unsolved problems.

The most immediate needs for the advance of the science are (a)the collection of additional basic data along various lines, (b) correlative research and coordination of existing results, and (c) research to provide connective tissue between related problems.

The most general problem is that involved in the transition from a qualitative to a quantitative basis, a change which is going on apace in all physical sciences.

The shattering of ancient idols of belief by the iconoclastic methods of experimental research has left science chary of accepting as definitive knowledge anything that has not been tested quantitatively and then checked and double-checked. Yet the outlook for hydrology is hopeful. There is enough of established fact and principle to afford a suitable framework for the main structure of the science and the very conditions cited create an opportunity for rapid progress.

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Voorheesville, New York

SIGNIFICANT STUDIES IN HYDROLOGY ON THE PACIFIC COAST

W. W. McLaughlin

Information that I was to appear upon this program did not reach me until after the trip East was more than half over. Data to make such a paper at all complete are nearly 3,000 miles away and for this reason only the most general statement is possible and no bibliography is attempted.

The work in hydrology now in progress in the West, conducted by the Division of Agricultural Engineering, either independently or in cooperation, and that will be conducted after July 1 of this year by the new Bureau of Agricultural Engineering, will be briefly summarized.

The present Los Angeles aqueduct from Owens Valley cost approximately $23,000,000 for the conveyance of 420 second-feet of water. This is an approximate cost for conveyance alone of $55,000 per each second-foot.

The aqueduct to carry water from the Colorado River 252 miles to the Metropolitan Water District at Los Angeles is estimated to cost $199,800,000. The conduit is designed to carry about 1,600 second-feet of water and the conveyance charge in this instance is approximately $123,750 per second-foot, a rather high cost where water is to be used partly for irrigation, as in this case.

In one of the recent developments of the Pacific Gas and Electric Company in northern California, the conveyance cost for water used in the development of hydro-electric energy is approximately $60,000 for each second-foot conveyed.

To meet problems of water-conveyance, we are studying the laws governing the flow of water in artificial commercial conduits constructed of metal, wood, concrete, in earth, etc., and the physical factors that affect the rate of flow of water in these conduits, such factors, for instance, as size, shape, slope, curvature, and age of such conduits, and the degree of roughness of their inner surface.

At the present time the Los Angeles City Water Department is hand-troweling the inner surface of a part of the Owens Valley conduit, that the carrying capacity may be increased from 420 second-feet to an estimated capacity of 478 second-feet, or 13 per cent. This 13 per cent represents approximately $3,000,000 in conveyance-charges, based upon the original cost of the conduit. If by further studies we can determine a method of construction that will permit a similar saving in the Metropolitan water-conduit, there would be represented a saving in conveyance-cost of $26,000,000, a sum that would pay for a large amount of research-work.

In the Santa Ana basin of southern California we are able to account for but 22 per cent of the total rainfall on the watershed, of which, during spring floods, six per cent runs directly into the ocean. It was proposed to expend $16,000,000 for the purpose of impounding this six per cent of water in a surface-reservoir from which there would be considerable evaporation. It has occurred to us that it might be possible to conserve a part of the unmeasured 78 per cent of this rainfall. Transpiration- and evaporation-losses might be reduced very materially by confining the river channel, reducing seeped and water-log areas and by reducing the amount of nonvaluable vegetative growth, drinking directly from these waters. For instance, the amount of water transpired annually by an acre of cat-tails is sufficient to take care of the annual irrigation requirements of 7 to 10 acres of oranges, or 4 to 6 acres of alfalfa, or 15 to 20 acres of grapes. We are determining by means of soil-moisture studies the movement within the soil of moisture from natural precipitation and from water applied artificially and thereby acquire information as to the consumption of this water by plant-growth. We learn the water usage of crop-plants, as well as of native vegetation. This transpiration-loss for many plants is greater and in some instances many times greater than is the evaporation-loss for similar areas of open water.

The present technique of studying the movement of moisture within the soil, whether such movement be due to transpiration by plants or by the action of gravity or by capillarity or by any combination of these, has been developed almost wholly by our irrigation workers or those with whom we are associated. The same is true of equipment used in taking soil-samples.

In the Santa Ana basin there is produced annually by irrigation from $80,000,000 to $100,000,000 worth of agricultural products. Of the water used in irrigation in this area approximately 75 per cent is pumped from underground reservoirs. The cost of applying water in some sections of this area runs from $100 to $150 per acre annually, and the cost is rather continuously increasing these dry years due to the lowering of the water-table. We are studying means of augmenting the present natural contribution

to the underground supply very largely by means of spreading flood-water. For the most part this water is spread over gravelly cones at the mouth of canyons and ravines. We are also determining to what extent rainfall upon the valley-floor contributes to the underground water-supply. In our water spreading we are determining the rate of percolation upon areas where there is natural vegetation of brush and grass, and the rate of percolation where this vegetation has been removed, and where the ground has been plowed. Also the rate of infiltration where the water is impounded within dikes or run into basins dug in the gravelly material. Studies are being made upon the rate at which water may be disposed of by running it into shafts of different sizes dug to various depths. We are determining to what extent the rate of infiltration is affected by temperature and by barometric pressure, by silt-laden water, and by water containing different electrolites. For instance, the rate of infiltration on brush- and grass-covered areas is on most of our plots from two to four times greater than on similar areas of plowed land. The get-away from shafts is a rather constantly decreasing amount within certain limits. A wind-storm in the San Fernando Valley will blow sufficient dust into the settling-basins in one day to almost completely stop infiltration of water.

Silt, sand, gravel, and other debris are menaces to our irrigation-systems. For instance, the Imperial Irrigation District will spend in a single year $1,000,000 in removing sediment from the canal-system. In the mountain states spring-floods and cloudbursts completely fill considerable stretches of canals with debris. We are studying the laws governing the transportation of this material by water and means of prevention, such as the effect of check-dams, etc. In the Colorado hydraulic laboratory we are developing a means of ridding canals automatically of the bed-load, usually of sand.

The agricultural salvation of arid areas is its irrigation, which means water-supply. The water-supply of the West for the most part originates upon the upper reaches of the watershed and the irrigator is commencing to realize his fundamental interest in the watershed and its problems, as well as its control for water-production. We are therefore extending our studies into the watershed-areas.

Evaporation, transpiration, surface-runoff, deep percolation, and soil-storage are the chief means for the disposal of natural precipitation. We are studying all of these. Our evaporation-studies had as their purpose the development of a formula which will permit converting the data obtained from pans of different sizes to its equivalent for reservoirs and other areas of open water. Not only are we interested in evaporation-losses from relatively pure water, but losses from water containing appreciable amounts of different salts. We have determined in Colorado that a water containing five per cent, by weight, of sodium chloride has approximately the same evaporation-rate as water containing no appreciable quantity of this salt. It is expected to continue the study using different combinations of various salts.

In drainage-studies in the West we have been confused many times as to the source of water that was causing trouble. One such area is in northern Utah in an artesian basin. Here it has been demonstrated by actual test that the water causing water-logging was coming up through about 40 feet of water-laid silt and clay. Relief-wells and pumping-plants were installed and the effect of each stage of development measured. Springs that have flowed continuously since before the knowledge of men have been dried up in these operations and the flow of these springs revived by plugging the wells and stopping the pumps. Wells of different diameters have been put down to determine the effect of diameter upon water-yield. While it has not been possible to improve upon Stokes' law, it has been clearly demonstrated that this law is useful in underground-water studies where pumping is involved.

In many sections of the West artesian water is water-logging agricultural lands and the drainage of these lands is readily accomplished by reducing the hydrostatic pressure. In the brief time allotted to me it is not possible to give more than a most general statement concerning our work in hydrology. While much of the discussion has related to California, it has been because data are more available and I have in mind these records more clearly than for other areas. Much of our work extends to many of the other states of the arid regions. No attempt has been made to tell of flood-control and other problems of hydrology now being investigated by State and other agencies, nor of the work of the Water Resources Branch of the Department of the Interior, the Army Engineers, or the Forest Service.

The State-wide water development plan of California is an excellent example of the interest developing along some branches of hydrology. City, County, and State agencies of the West are developing water-supplies for municipal and agricultural uses by the diversion and storage of surface-waters, the pumping of water from below the ground-surface and, in rare instances, attempting to wring rain from the cloudless skies.

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HYDROLOGICAL STUDIES IN THE BLACK RIVER DRAINAGE-BASIN, NEW YORK

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The systematic measurement of the principal hydrological factors affecting stream-flow was undertaken by the engineers of the Black River Regulating District about five years ago in an effort to improve the operation of a system of storage-reservoirs under construction for river-regulation. The measurement of rainfall and stream-flow had already been carried on for a considerable number of years, but it was believed that records of temperature, wind, humidity, evaporation, ground-water stage, and possibly other factors would lead to better results in predicting the runoff to be expected from a known quantity of rainfall or from a known accumulation of snow at the end of the winter season. It is my purpose to outline the work now being carried on and to ask for your suggestions for the improvement of future work.

The Black River drains an area of about 1,900 square miles on the westerly slope of the Adirondack Plateau in New York State. Rising at an altitude of about 2,000 feet, the River flows in a general westerly direction and empties into Lake Ontario near the head of the St. Lawrence River. The mean annual rainfall over the drainage-basin is about 47 inches and the runoff 26 inches. The loss, therefore, is 19 inches or about 50 per cent of the precipitation. The easterly section of the watershed is somewhat mountainous and is well wooded, while the lower reaches consist of farm land. The prevailing rock consists chiefly of dense impervious gneisses and schists, which are overlain, in the lower reaches, by limestones and shales. Deposits of glacial drift of varying depth cover most of the underlying rock.

Between the Black River Valley and Lake Ontario, a ridge of sedimentary rock, locally known as Tug Hill, rises to a height of about 2,000 feet above sea-level. As the prevailing winds are from the west and southwest, this ridge has a dominating influence on the precipitation over substantially the whole watershed of the Black River.

The hydrological work now being carried on includes the measurement of stream-flow at eleven stations distributed over all the principal streams of the watershed; rainfall at seventeen stations; temperature at six stations; wind-velocity and daily movement at three stations; humidity at two stations; evaporation from two standard 48-inch land-pans; and ground-water stages in fourteen wells situated in the glacial sands of the upper reaches of the watershed. Snow-surveys, showing the depth of snow and its water-equivalent in inches, are made three or four times during the winter and early spring. A sunshine-recorder is maintained at Wanakena, but not at McKeever.

The available rainfall- and streamflow-records vary in length from more than 30 years to less than one year, but most of the records of the other hydrological factors were begun in 1926. Two reasonably complete stations were established in that year, one at McKeever, near the southerly margin of the drainage-area, and the other at Wanakena, just north of the Black River Watershed. The latter station is operated by, and in cooperation with, the State Ranger School, a department of the State College of Forestry at Syracuse University. Both stations are equipped with rain-gages, maximum and minimum thermometers, psychrometers, recording hygro-thermographs, anemometers, and 48-inch evaporation-pans.

In addition to the above-described station at Wanakena, the Ranger School maintains six other stations in different types of forest growth, at which precipitation, temperature, humidity, ground-temperature, ground-moisture, and other factors affect-

ing tree-growth are measured. These records also have very courteously been made available by the faculty of the Ranger School.

The records of the past five years are now being worked up for preliminary study, but it is yet too early for any attempt to formulate conclusions. Of the past five years, four were wetter than normal, but the last year was considerably dryer than normal. The records are being tabulated for comparison by months, years, and seasons. Graphic methods are being used wherever possible.

It is expected that when a sufficient length of record has been accumulated to warrant tentative conclusions, the records will be offered for publication. In the meantime the speaker would be glad to know of other similar efforts to correlate the factors which are responsible for the chief losses between precipitation and runoff.

Black River Regulating District,
Watertown, New York

INVESTIGATIONS RELATING TO THE ABSORPTION OF PRECIPITATION AND ITS PENETRATION TO THE ZONE OF SATURATION

O. H. Taylor

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This paper deals briefly with the methods and results from three separate investigations that are in progress as to the quantity of rain-water that percolates downward to the water-table in the localities where it falls.

1. Workers in the Department of Agriculture, under the direction of W. W. McLaughlin and in cooperation with the California State Department of Public Works, have used several related methods to intercept and measure the rainfall-penetration. H. F. Blaney and C. A. Taylor have conducted these tests near Los Angeles. A report covering this work, with H. F. Blaney, C. A. Taylor, and A. A. Young as co-authors, will be published in the near future as a bulletin by the State of California, Department of Public Works, Division of Water Resources. Rough sketches of some of the apparatus used are shown in Figures 1 and 2.

Figure 1 shows how a 3 by 3-inch or 3 by 12-inch cylinder was jacked into the roof of a tunnel, with a collecting-basin placed under the cylinder. Figure 2 shows two types of trough-shaped intercepting-pans that were jacked into the sidewalls of a pit. Only a very small drip was obtained from either type of apparatus, and a test was made to determine where the moisture was going after being applied to the surface.

A setup as shown in Figure 3 was installed. This consisted of one of the types of pan shown in Figure 2, set about two feet under the ground-surface. A bottomless pan of the same horizontal area as the intercepting-pan was set directly above the intercepting-pan. Enough water was applied to the confined area directly above the intercepting-pan to penetrate to a depth much greater than that at which the pan was

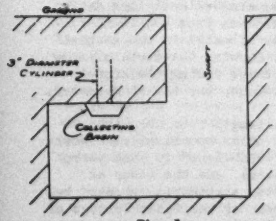

Fig. 1

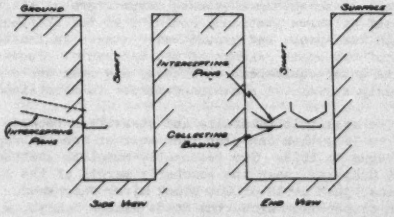

Fig. 2

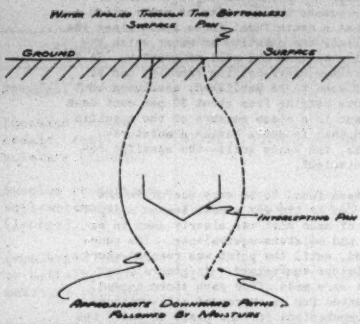
Water Applied Through The Bottomless Sample Pan
Ground Surface
Intercepting Pan
Approximate Downward Paths Followed By Moisture

Fig. 3

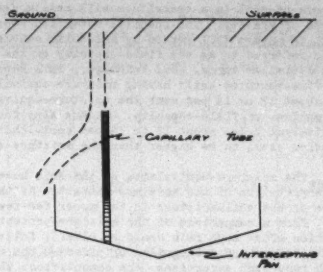

Fig. 4

set. No appreciable amount of drip was obtained. A trench was then cut through the center of the installation, and the moisture-content of the soil at intervals in the trench-face was determined. The moisture was found to be passing around the intercepting-pan, somewhat as shown by the dotted lines in Figure 3. An explanation of why this was happening may be illustrated by the sketch in Figure 4.

The intercepting-pan as shown is surrounded by soil and sand. The interstices throughout the soil and sand, although not forming an actual capillary tube, have a similar action through interconnecting pores. Figure 4 shows one series of these connecting pores as a small capillary tube. As the moisture moves down toward the intercepting-pan, it enters these capillary tubes and when it comes into contact with the pan it can not drain farther downward. The tubes then begin to fill and build up a head of water. Before any drip from the intercepting-pan can take place, the head in these tubes must be high enough to cause the moisture to move out of the bottom of the tubes and form a water-table on the pan. But the level of the capillary water rises above the edges of the intercepting-pan as the head is built up in the tubes, allowing the moisture to escape through other connecting interstices around the rim of the intercepting-pan. Additional moisture coming from above then moves around the pan instead of being intercepted. Thus, the edges of the intercepting-pan must be high enough to exceed the height of the capillary fringe in the material being investigated, before an appreciable amount of drip will be obtained.

This method was abandoned and the problem attacked by determinations of soil-moisture. The improved soil-sampling tube was selected to obtain the soil-samples. The pioneer work of developing this tube was done at Davis, California, by Dr. F. J. Veihmeyer of the University of California, who has described this tube in Soil Science, February 1929. Messrs. Blaney and Taylor of the Department of Agriculture assisted in later developments of the apparatus and contributed greatly in devising other apparatus to be used in connection with the tubes. Reliable soil-samples can rapidly be obtained by using this type of soil-sampler, even in very hard material, and an accurate record of the changes in moisture-content of the soil can be made. The soil can readily be sampled to a depth of 12 to 14 feet, and C. A. Taylor has sampled to depths of 18 feet.

2. The United States Geological Survey, in cooperation with the East Bay Municipal Utility District of Oakland, California, is engaged in an investigation of the geology and water-resources of the Mokelumne River area, which lies in the San Joaquin River valley between the cities of Stockton and Sacramento. An investigation of the penetration of rainfall in this area is in progress, in which the method of making determinations of soil-moisture has been adopted after the work by the Department of Agriculture in southern California. The soil-samples have been obtained in one-foot increments to a maximum depth of 13 feet, by use of the soil-sampling tubes.

Moisture-equivalent tests were also made under the direction of Dr. Veihmeyer for this investigation. The moisture-equivalent represents the quantity of water which a sample of soil in a centrifuge will retain against a centrifugal force 1,000 times the force of gravity. The specific retention represents the quantity of water which the soil in nature will retain by molecular attraction against the pull of gravity. It is also referred to as the field-capacity or the maximum water-holding capacity and by other similar terms. Dr. Veihmeyer, in a report soon to be published, concludes that in fine-textured soils having moisture-equivalents ranging from about 30 per cent down to about 12 or 14 per cent the moisture-equivalent is a close measure of the specific retention, or field-capacity. He has also found that in soils having a moisture-equivalent below about 12 to 14 per cent--that is, the sandy soils--the specific retention seems to be higher than the moisture-equivalent.

The moisture-equivalents of the soil have been found to be very useful in the interpretation of the moisture-content. At the end of the dry summer season a depletion of the soil-moisture in the upper few feet of each plat was clearly seen to exist, from a comparison of the moisture-contents and moisture-equivalents. The penetration after each rain could be clearly followed, until the point was reached where the moisture-content equaled or exceeded the moisture-equivalent. In general, but with important exceptions, the computations that were made after each storm showed that nearly all of the rain-water could be accounted for as increased soil-moisture until the zone of depletion was replenished. Computations for the plats in which the soil-moisture depletion was satisfied before the end of the rainy season showed substantial deficits--that is, amounts of rain-water that could not be accounted for by increase in soil-moisture or by soil-evaporation. These deficits could best be explained on the theory that, in addition to the moisture lost by evaporation, some of the soil-moisture escaped by downward percolation beyond the depth of 13 feet. On plats having no vegetation moisture that penetrates to depths of more than 13 feet eventually reaches the water-table and is added to ground-water storage. Ten rainfall-penetration plats, which were kept free of vegetation, were maintained during the season of 1929-30. The rainfall at these plats ranged during the season from 10 to 13 inches. At eight of the plats some recharge was indicated, but some of these had been irrigated in the previous summer and were consequently not as completely dried out as they would otherwise have been.

In order to illustrate the methods used in the interpretation of the data a detailed analysis of the results obtained at the Zechmeister plat follows. It should be frankly stated, however, that the data obtained from some of the other plats do not lend themselves to as satisfactory interpretations as those of the Zechmeister plat. Tables 1 and 2 give the base-data from the Zechmeister plat.

Table 1--Observations on Zechmeister plat, October 29, 1929 to May 15, 1930
(Moisture-equivalent in columns headed A and moisture-content in columns headed B are expressed in inches of water in each foot of soil)

Date	Oct. 29		Dec. 13		Dec. 26		Jan. 10		Jan. 22		Feb. 27		Mar. 10		Apr. 25		May 15	
Depth sampling	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
ft	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in
0-1	1.52	0.41	1.52	1.86	1.52	2.15	1.48	2.58	1.48	2.32	1.48	2.64	1.51	2.09	1.36	1.03	1.32	0.80
1-2	1.32	0.43	1.22	0.59	1.19	0.99	1.35	2.04	1.32	1.94	1.35	1.91	1.39	1.89	1.28	1.17	1.15	0.92
2-3	1.23	0.55	1.22	0.59	1.25	0.60	1.26	1.02	1.32	1.91	1.28	1.61	1.39	1.92	1.26	1.23	1.20	1.05
3-4	1.37	0.58	1.32	0.64	1.29	0.67	1.23	0.65	1.38	1.58	1.32	1.58	1.35	1.85	1.31	1.31	1.19	1.18
4-5	1.29	0.66	1.36	0.84	1.29	0.84	1.26	0.81	1.32	0.96	1.38	1.47	1.35	1.80	1.32	1.39	1.42	1.50
5-6	1.45	0.94	1.52	1.14	1.55	1.17	1.68	1.22	1.62	1.21	1.48	1.34	1.57	1.38	1.48	1.66	1.55	1.70
6-7	1.60	1.50	1.72	1.66	1.60	1.47	1.74	1.59	1.62	1.53	1.55	1.55	1.77	1.68	1.71	2.16	1.56	1.98
7-8	1.36	1.90									1.19	1.68	1.26	1.68	1.22	1.90	1.16	2.15
8-9	0.52	0.76									0.61	0.71	0.67	0.74	0.71	0.95	0.64	0.96
9-10	0.26	0.47									0.32	0.39	0.38	0.41	0.67	0.75	0.38	0.55
10-11	0.32	0.53									0.29	0.47	0.35	0.44	0.45	0.68	0.25	0.44
11-12	0.26	0.55									0.25	0.60	0.29	0.61	0.32	0.51	0.26	0.51
12-13	0.26	0.52													0.29	0.51	0.29	0.48

Table 2--Summary of data from Zechmeister plat

Element	Oct.29-Dec.13	Dec.13-Dec.26	Dec.26-Jan.10	Jan.10-Jan.22	Jan.22-Feb.27	Feb.27-Mar.10	Mar.10-Apr.25	Apr.25-May 15
Rainfall (inches)	1.40	0.90	1.83	2.28	1.85	1.50	0.70	0.28
Increase or decrease, soil-moisture (inches)	+1.61	+0.70	+1.88	+1.61	+0.63	+0.31	-1.47	-1.05
Surplus or deficit, soil-moisture (inches)	+0.21	-0.20	+0.05	-0.67	-1.20	-1.19	-2.17	-1.33
Cumulative surplus or deficit, soil-moisture (inches)	+0.21	+0.01	+0.06	-0.61	-1.81	-3.00	-5.17	-6.50
Depth used in computations (feet)	2	3	4	5	6	7	12	13
Evaporation from a free-water surface, Oakdale, Calif.[a] (inches)	4.32	0.44	0.61	0.23	2.03	1.13	6.76	3.93
Probable depth of rainfall-penetration (feet)	1+	2	3	4+	6+	....	....	....

[a] From records of the United States Weather Bureau.

Notes on data of Tables 1 and 2--October 29 to December 13: The rainfall was 1.40 inches and the increase in water in the upper two feet was indicated to be 1.61 inches. As the soil was very dry before the first rain there was probably not much evaporation, and the indicated surplus does not involve any great experimental error. Practically all the rain that penetrated was stored in the first foot or the upper part of the second foot, bringing the moisture-content of the first foot above the moisture-equivalent and probably above the specific retention.

December 13 to December 26: The rainfall of 0.90 inch in this period increased the moisture in the upper three feet by 0.70 inch, leaving a computed deficit of 0.20 inch. This deficit doubtless involves an experimental error but may represent approximately the loss by evaporation. The added moisture was stored in the upper two feet, and the penetration of the rainfall was about two feet.

December 26 to January 10: The rainfall during this period was 1.83 inches, which gave a computed increase of water stored in the upper four feet of 1.88 inches, or a surplus of 0.05 inch. This surplus, together with such evaporation as may have occurred, is within reasonable limits of experimental error.

January 10 to January 22: A rainfall of 2.28 inches increased the computed quantity of water stored in the upper five feet by 1.61 inches. The deficit was therefore 0.67 inch, which is somewhat more than can be accounted for by evaporation from the soil but is not regarded as involving an excessive experimental error. The rain penetrated through the fourth foot and entered the fifth foot.

January 22 to February 27: A rainfall of 1.85 inches increased the computed moisture content of the upper six feet by 0.63 inch, leaving a deficit of 1.20 inches, which must be accounted for chiefly or wholly by soil-evaporation and experimental error. The rain penetrated through the fifth foot and entered the sixth foot. Replenishment of the zone of depletion was nearly or wholly completed.

February 27 to March 10: A rainfall of 1.50 inches increased the moisture content of the upper seven feet by 0.31 inch, leaving a deficit of 1.19 inches. The deficiency in the moisture-content was apparently satisfied throughout the entire soil-column under test. The soil had virtually no more storage-capacity, and it might be expected that water added by future rains would cause downward percolation. It appears probable that the deficit of 1.19 inches is not due entirely to evaporation and experimental error, but that some water was at this time percolating downward.

March 10 to April 25: There was a rainfall of 0.70 inch during this period and the storage in the 12-foot column was decreased by 1.47 inches, making a computed deficit of 2.17 inches. During this period the evaporation from a free-water surface was high, and there was a notable decrease in soil-moisture near the surface. Both of these conditions suggest that a large part of the deficit is due to evaporation from the soil. The increase in moisture-content in the material below the fifth foot indicates downward percolation.

April 25 to May 15: The rainfall in this period was 0.28 inch, and the moisture-content of the 13-foot column decreased 1.05 inches, giving a total computed deficit of 1.33 inches. The light rainfall was apparently not sufficient to replace the deficiency in the moisture-content of the upper four feet caused by evaporation. The decrease in the moisture-content of some of the material below the fourth foot suggests percolation below the thirteenth foot. The decrease of moisture-content of the material between the sixth foot and the thirteenth foot was 0.32 inch, which may be due in part to experimental error but is nevertheless suggestive of downward percolation.

The complete results from all rainfall-plats operated during the rainy season of 1929-30 are on file in the office of the Geological Survey.

During the season of 1930-31 only four rainfall-plats have been kept in operation, the smaller number permitting of more intensive sampling. One plat is also in operation to determine an approximate figure to assign to soil-evaporation.

3. Recently W. N. White, of the United States Geological Survey, in cooperation with the Board of Water Engineers of Texas, has made two tests in the Winter Garden area of Texas, using buried lysimeters to obtain the amount of rainfall penetration. The method that he used is illustrated in Figure 5. The lysimeters are water-tight cylindrical vessels 4 to 6 inches in diameter and about 18 inches high, with open tops. They were placed at the ends of 3- or 4-foot tunnels driven in the sides of pits dug to the desired depth. The lysimeters were filled with material similar to that removed from the tunnels and were packed to approximately the same density. The weight of each cylinder and the material that it contained was determined. With an improvised screw-jack, each lysimeter was then jacked tightly against the roof of the tunnel to make good contact between the material in the roof of the tunnel and the material in the lysimeter. The entire tunnel was then repacked with the material that was taken from it, and the pit was filled flush with the surface of the ground. It is necessary to repack the tunnel so that the moisture may have an uninterrupted downward path to follow in the immediate vicinity of the lysimeter. Otherwise, moisture would accumulate to some extent along the roof of the tunnel, and an excess amount of moisture might be collected in the lysimeter because of the capillary action already described. The shaft was filled to prevent complications that might arise from the drying along its walls.

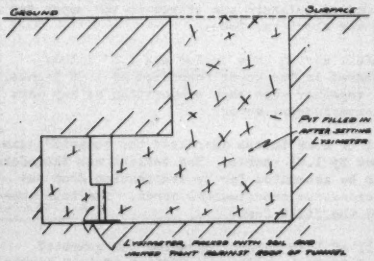
GROUND
SURFACE
PIT FILLED IN AFTER SETTING LYSIMETER
LYSIMETER, PACKED WITH SOIL AND JACKED TIGHT AGAINST ROOF OF TUNNEL

Fig. 5

After three or four weeks had elapsed and considerable rain had fallen in the locality, the lysimeters were dug out and reweighed. One of the lysimeters that had been placed ten feet below the surface and was under a cover of four feet of sandy top-soil, four feet of rather hard sandy

clay, and two feet of hard sandstone, gained enough in weight to indicate an accretion of about four inches of water. The other lysimeter, placed about six feet below the surface, under a cover of about three and one-half feet of sandy soil and about two and one-half feet of hard sandy clay, also gained enough in weight to indicate an addition of about four inches of water. The material under which these lysimeters were placed can be classed as rather permeable. Other lysimeters are now being placed under soils of other types in the Winter Garden area.

The chief difference between the lysimeters used by White and the intercepting and collecting pans used in southern California is that in White's lysimeter it is not necessary to obtain a water-table or free gravity-water. It is possible by weighing to obtain the amount of moisture that has entered the lysimeter, even though sufficient head has not been built up in the capillary tubes to produce free gravity-water. In order to determine the total amount of water that is percolating downward it is necessary to remove the lysimeter and weigh it before the capillary pores have been filled to the top. Where there is much downward percolation it is necessary to use a rather high lysimeter or else to remove it at frequent intervals.

U. S. Geological Survey,
Lodi, California

GLACIER-MEASUREMENTS IN THE UNITED STATES

Francois E. Matthes

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It is doubtless known to many members of the Section of Hydrology that prior to the World War there existed an International Glacier Commission (la Commission Internationale des Glaciers) whose self-appointed task it was to gather and publish the results of all available measurements showing the annual variations in length--advance or recession--of glaciers in different parts of the world. On this Commission the United States was represented by two men who made frequent contributions to the International record.

The World War in 1914 put an end to the activities of this International Glacier Commission, and for thirteen years thereafter no organized effort was made to collect or publish any results of glacier-measurements. In 1927, however, the newly created Union of Geodesy and Geophysics, through its Section of Scientific Hydrology, revived the work. That Section, indeed, organized a new Glacier Commission headed by Professor Hamberg of Sweden, President, Professor Rabot of France, Vice-President, and Professor Mercanton of Switzerland, Secretary, and to this new Commission all the records and files of the old one were transferred. Its first task was, naturally, to make up as well as it could for the 13-year lapse in the functioning of the old Commission, and accordingly it published in 1930 through the International Union of Geodesy and Geophysics a volume in which were brought together all the figures on European glaciers that were available for the period 1915 to 1928. In spite of the fact that these figures are necessarily incomplete, especially for the war-period, and are published without any detailed information concerning the measurements on which they are based, it is safe to say that every student of glacier-variations will hail with satisfaction the appearance of these data in simple and convenient tabulated form. Certainly it is to be hoped that the new Glacier Commission will be permitted to continue its work without interruption from year to year and that it will stimulate observers everywhere to make their annual measurements with unfailing regularity, if possible, so as to give the cumulated record the greatest possible value to science.

In this connection may I offer the suggestion that it would be appropriate and timely for us to emulate the example of our European brethren and set up an agency for the systematic recording of glacier measurements in this country. Our Section of Hydrology, it seems to me, would be the logical agency for this kind of work, just as the Section of Scientific Hydrology of the International Union of Geodesy and Geophysics is the agency that carries it on abroad. The reports of our Section, published annually through the American Geophysical Union, would then become the medium

to which students of glaciology, hydrology, and climatology the world over would turn for the record of American glaciers, just as they now turn to the annual reports of the International Union for the record of European glaciers.

Perhaps it would be pertinent here to add a word in regard to the propriety of bringing such activities as recording glacier-measurements within the scope of work of this Section of Hydrology. The science of hydrology, it is true, deals in the main with water in the liquid state, but it can not ignore altogether that portion of the water which for considerable lengths of time is locked up in the solid state in glaciers and ice-sheets. For, in the first place, every glacier is inherently the source of a stream. In some mountain regions, indeed, the glaciers are the principal sources of water-supply, and upon them largely depends the welfare of the communities and industrial developments that man has built up. It is therefore a matter of direct practical and economic import to ascertain to what manner of fluctuations the glaciers in such regions are subject--whether they are doomed to a progressive decline and ultimate extinction, and if so, at what rate the decline will take place, or whether they are on the increase, or merely subject to cyclic variations. A case in point will be adduced farther on in this paper.

In addition to these essentially practical considerations there are those far-reaching considerations of a theoretical nature having to do with the broad field of climatic variations. For the oscillations of glaciers afford, when studied synthetically over large portions of continents or over entire continents, valuable indices of climatic changes that are now in progress. Glaciers are, in fact, extremely sensitive registers of climatic variations and often show them up more vividly than streams or vegetation. To the hydrologist who would consider the subject of water-supply in its broadest aspects and with an eye to future conditions, therefore, the records of glacier-oscillations are likely to have special value.

It might be urged that other lines of glacier-study also be included in the work of the Section of Hydrology. There are perhaps good reasons for doing so, especially in view of the absence of a Section of Glaciology, either in the American Geophysical Union or in any other scientific organization of national scope. But the suggestions conveyed in this paper with regard to the recording of glacier-measurements are already so comprehensive that it seems best for the present to limit ourselves to them.

The United States has at no time in the past made any large contributions to the International record of glacier-measurements. This is not because it lacks glaciers--there are hundreds of small glaciers in the Rocky Mountains and on the Cascade Range, and there are innumerable glaciers, large and small, in Alaska. The principal reason for the scantiness of our contributions hitherto is unquestionably that the vast majority of American glaciers have been heretofore very difficult of access. Today, however, the conditions are much more favorable than formerly, many parts of the country that were once considered remote being opened up by routes of travel. Within the last two decades some of the finest glaciers in the United States, including Alaska, have been made readily accessible, and thus the physical obstacles in the way of a comprehensive plan of glacier-measurements are gradually disappearing.

It might be appropriate here to take stock, so to speak, of the American glaciers that are now available for annual study, but the limits of this paper preclude the inclusion of such a list. Suffice it to point out that, whereas the glaciers south of the Canadian boundary are mostly small, those in Alaska are developed on a grand scale and include a variety of different types, so that, taken as a whole, the array of American glaciers available for systematic study far surpasses that of Europe. This may be a matter of pride with us, but it also entails a correspondingly heavy obligation on our part to science. If we possess such a wealth of glaciers, our contributions to the International record should be greater than they are.

The prime difficulty is, of course, to find men willing to make the measurements and to repeat them faithfully year after year. While the actual work of measuring from a base-line to the ice-front is in most instances not arduous, once the base-line has been established, the persistent repetition of measurements every year requires a dependable organization of some sort and a will to carry on.

Fortunately a good beginning has been made in our Pacific Northwest. In two localities, on Mount Hood and on Mount Rainier, glaciers are now being measured annually with reference to permanent base-lines laid out for the purpose. In both instances science is indebted to volunteers, themselves not glacialists or hydrologists, yet who with fine enthusiasm and a realization of the worthwhileness of the work, carry it on faithfully, from year to year. The Mazamas, the mountaineering-club of Portland, Oregon, have assigned themselves the task of measuring the glaciers on Mount Hood; the National Park Service has for a number of years measured the Nisqually Glacier, on Mount Rainier.

The records of the Research Committee of the Mazamas show that in 1926 the Eliot Glacier, an ice tongue about 2.5 miles long on the northeast side of Mount Hood, receded a distance of 30 feet, but that since then the ice-front has remained practically stationary in spite of the fact that the glacier has suffered some reduction in thickness by melting. More recently the Mazamas have laid out base-lines controlling the termini of the Ladd and Coe glaciers, which radiate to the north-northwest and to the north, respectively, on the cone of Mount Hood. Both these glaciers, which are somewhat shorter than the Eliot, have remained essentially unchanged in length during 1929 and 1930.

Entirely different is the record of the Nisqually Glacier on Mount Rainier. This glacier, which measures 4.6 miles in length and may be regarded as representative of the eleven main glaciers on the peak, has been in constant recession ever since it was first viewed in 1857. The measurements of the National Park Service show that the Nisqually's terminus has receded a total distance of 748 feet in the 11-year period from 1918 to 1929. The mean annual recession was about 68 feet. As is clear from the table furnished by the Park Service, the actual yearly recessions have varied from a minimum of 43 feet (in 1926-1927) to a maximum of 106 feet (in 1920-1921).

Recession of Nisqually Glacier

1857-1885 (estimated)	760 feet	1922-1923 (measured)	44 feet
1885-1892 (estimated)	140 feet	1923-1924 (measured)	83 feet
1892-1918 (estimated)	1,310 feet	1924-1925 (measured)	73 feet
1918-1919 (measured)	59 feet	1925-1926 (measured)	86 feet
1919-1920 (measured)	46 feet	1926-1927 (measured)	43 feet
1920-1921 (measured)	106 feet	1927-1928 (measured)	89 feet
1921-1922 (measured)	67 feet	1928-1929 (measured)	52 feet

For the years prior to 1918 no accurate measurements are available, but there are observational data that afford a fairly good basis for estimates. In 1885, according to the testimony of some of the early settlers at the foot of Mount Rainier, the Nisqually Glacier reached down to the site of the present highway-bridge across the Nisqually River. Lieutenant A. V. Kautz, who in 1857 made the first attempt to climb the peak, described the Nisqually Glacier as terminating at a narrow throat in the canyon which is readily identified and is about 760 feet below the site of the bridge. Thus it is reasonably certain that the glacier melted back 760 feet during the 28-year period from 1857 to 1885--that is, at a mean rate of a little over 27 feet per annum. Again, it is fairly definitely known that in 1892 the terminus of the glacier lay about 140 feet above the bridge-site. During the 7-year period from 1885 to 1892, therefore, recession took place at a mean rate of 20 feet per annum. According to the data of the Park Service, the glacier receded no less than 1,310 feet during the 26-year period from 1892 to 1918, or at a mean rate of 50.4 feet per annum. A check on this rapid increase in the rate of recession is afforded by the fact that in 1910, when the writer was making the topographic survey of the Mount Rainier National Park, the Nisqually Glacier ended about 1,000 feet above the bridge. As it ended at a point about 140 feet above the bridge site in 1892, there must have been a recession of 860 feet during the 18-year period from 1892 to 1910--that is, at a mean rate of 47.8 feet per annum. It is noteworthy that the rate is more or less constantly on the increase, the mean for the period 1918 to 1929 mounting to 68 feet per annum.

The total recession for the 72-year period from 1857 to 1929 is 2,958 feet or practically 3/5 mile. This is truly a startling figure. If recession should continue in the future at the mean rate for the entire period mentioned (about 41 feet per annum), the Nisqually Glacier would cease to exist in 410 years. If recession should

continue at the mean rate for the last eleven years (68 feet per annum) the glacier would vanish in 357 years. Of course it is highly improbable that the glacier would utterly vanish in that time, or in twice that time; for unless there is a radical change in climate, the rate of recession is bound to diminish progressively as higher altitudes are reached, and some snow and ice are therefore likely to linger on and about the summit of the peak for an indefinite length of time. It is to be borne in mind that the Nisqually Glacier makes a total descent of more than 10,000 feet--from an altitude of about 14,400 feet to an altitude of somewhat over 4,000 feet--and that it traverses two climatic zones and reaches down into a third. The computations just made are based on a rate of melting that obtains only in the lowermost zone and greatly exceeds that in the higher zones.

It happens that the rapid recession of the Nisqually Glacier is at the present time a matter of special interest and even of concern, for the city of Tacoma depends upon the Nisqually River, which issues from the glacier, for hydroelectric power, and this river has shown an alarming diminution in discharge during the last few years. It would be rash, nevertheless, to attribute the lessened discharge of the river wholly or largely to diminution of the mass of the Nisqually Glacier. Indeed, the counter argument is entirely valid that the more substance the glacier loses by melting in summer, the greater will be the volume of water that flows from it. A great annual recession of the glacier's terminus and a concomitant reduction in its thickness, will mean, therefore, in general a great annual discharge for the stream. However, several other factors are involved, chief among which are variations in the annual snowfall that replenishes the glacier and the percentage of days of sunshine during the summer months. The snowfall-record at the Paradise Inn does not indicate any sharp diminution in the snowfall during the last few years (the record would have greater value in this connection if it were more complete and gave the amount of snow per winter instead of per year); hence it seems probable that prolonged periods of cloudy weather during the summer months have greatly retarded the melting and may be the principal cause of the decreased discharge of the Nisqually River.

It is not desired in this brief paper to go into an exhaustive discussion of this problem. The diminished discharge of the Nisqually River and its possible relations to the recession of the glacier are mentioned here rather as a sample problem, just as the recession-records of the Nisqually Glacier and of the smaller glaciers on Mount Hood are offered as samples of a class of data which, it is believed, will have considerable scientific value if collected systematically in many places and over long periods. Neither would it be profitable at this time to discuss the reasons for the contrasts in the behavior of the glaciers on Mount Hood and of the Nisqually Glacier on Mount Rainier during the same period, or to institute comparison between the records of these American glaciers and the records of European glaciers. Not until the glacier-records in the Pacific Northwest have acquired sufficient fullness and extend over sufficiently long periods to indicate climatic curves will their potential value be realized.

It seems appropriate, in closing, to stress the point that in the future, doubtless, as at the present time, we shall have to depend largely upon volunteers for the carrying out of annual glacier-measurements. Scientists will take a hand in some localities, but the work as a whole will fall upon men engaged in various occupations who dwell in the proximity of glaciers, or upon men who can afford to come annually from a distance on mountaineering-trips. If therefore in our opinion real importance attaches to the securing of unbroken records of glacial oscillations, it will behoove us to stimulate popular interest in the cause and to encourage and aid, at least with counsel, those who are willing to help.

In some parts of Europe, as in the French and Swiss Alps, the task of measuring the glaciers has for many years been borne by the men charged with the administration of the forests. Would it not be equally logical and appropriate in this country to invite the cooperation of the officers of the Forest Service and the National Park Service? The majority of the glaciers on our western mountains lie either within national forests or within national parks, and it cannot be doubted that measurements on them could be made by the men of these services with less outlay and personal effort than by anyone outside their domain. Already the officers of the Mount Rainier National Park have made a splendid contribution with their measurements on the Nisqually Glacier. Similar work carried on simultaneously in all the national parks and national forests containing important glaciers would be truly invaluable.

In some localities, perhaps, glacier-measurements might be undertaken by a university or college, especially by an institution of this kind having a department of geology or of surveying. Finally, some of the more active mountaineering-clubs might be induced to assume a share of the work. The Mazamas have led the way, and it is to be hoped that their fine example will inspire other organizations to follow them. Thus, if the Section of Hydrology should decide to make itself the central agency in this country for the assembling of glacier-data, it might in the course of time organize a widely scattered but efficient volunteer force to make the field-measurements.

U. S. Geological Survey,
Washington, D. C.

ORGANIZATION AND WORK OF THE UNITED STATES WATERWAYS EXPERIMENT STATION AT VICKSBURG, MISSISSIPPI

John Paul Dean

(Abstract)

The United States Waterways Experiment Station is a War Department activity, constructed and operated by the Corps of Engineers, United States Army, in connection with the design, construction, maintenance, and operation of flood-control works and river- and harbor-improvements, particularly for studies in connection with the comprehensive project for the control of the floods of the Mississippi River. The Waterways Experiment Station is on the outskirts of Vicksburg about four miles from the offices of the Mississippi River Commission. Its operations are controlled by Brigadier General T. H. Jackson, President of the Commission, under the general oversight of the Chief of Engineers, United States Army. The Director of the Station is First-Lieutenant Herbert D. Vogel, Corps of Engineers, who is especially prepared for this duty by education and training.

The Experiment Station is located on Durden Creek, a small tributary of the Mississippi, which drains most of the National Park on the site of the Vicksburg battlefield of 1863. An earth-dam has been built across the creek to impound about ten million cubic feet of water in a reservoir covering an area of 40 acres. The dam has a concrete spillway 120 feet long, together with control-gates for regulating the gravity-supply of water to the laboratory building and to the experimental field. Provision has been made for the use of flashboards on the spillway-crest when experiments are performed requiring an unusually large quantity of stored water. By the sudden removal of such flashboards an ample supply of water can be obtained for use in large models on lower Durden Creek.

The laboratory building is constructed of steel, brick, and concrete a short distance below the dam. It is 210 feet long and 50 feet wide and contains a laboratory, offices, carpenter-shop, experiment-hall, sediment-analysis laboratory, soil-laboratory, drafting-room, photographic dark-room, and an apartment for the caretaker. The main experiment-hall, 50 by 180 feet, occupies the central part of the building, and is illuminated by tall windows running the length of the hall. Steel roof-trusses leave the experiment-hall free from interior columns. Beneath the main room are measuring-basins, return-flumes, diversion-gates and flumes, pump-pits, sediment-traps, etc.

The main steel-flume runs the entire length of the building and through the end wall into an outdoor diversion-channel and an outdoor measuring-tank. The concrete floor of the hall slopes to a central grading for drainage, below which is a return channel also running the length of the building and emptying into either the measuring-basin or the waste-channel. Models are built on this floor in such form, size, and materials as seem most suitable for the purpose of the experiment. In flood-control models the river-channel bars, necks, and levees have been built to scale out of fine sand. All or part of the model is covered with a thin layer of mortar. Water flows from a storage-tank through baffles to the head of the model. Water-levels are observed at frequent critical points by point-gages and manometer-tubes. Tail-water elevations are regulated by a dam with hinged needles. Velocities are measured by floats, dyes, and pitot-tubes; current-directions by dyes, floats, and strings.

Sediment-movement and bar-formation is studied by the introduction of creosoted wood sawdust, which has been found very satisfactory in simulating the movement of natural river-sediment.

The experimental field is located downstream from the laboratory and has an area sufficient for the construction of outdoor models of all sizes. The native soil is loess, which stands indefinitely in vertical cuts and is easily carved into almost any shape. Using surveying instruments and sheet-metal templates cut to measured cross-section, the miniature stream is carved out of the natural soil with speed, economy, and accuracy sufficient for the purpose of the experiments. Where it is essential to hold the exact section under severe conditions of erosion, the earth-model is lined with mortar placed by a cement-gun or by trowel. Adjustments for distortion, scale-effect, roughness, variations, etc., are made as conditions require.

The location of the laboratory and experimental field near Vicksburg furnishes excellent facilities for experiments on major waterway-problems. Either clear or muddy water is obtainable, slopes can be varied at will. Extensive shops and warehouses of the Vicksburg district with experienced construction- and surveying-forces are available for the assistance of the laboratory.

Corps of Engineers,
United States Army,
Washington, D. C.

THE NATIONAL HYDRAULIC LABORATORY AT THE BUREAU OF STANDARDS

H. N. Eaton

(Abstract)

During the past half-century the method of model-tests has come to be applied in Europe as a powerful means of solving in the hydraulic laboratory complicated problems involved in the design of expensive hydraulic structures which could not be treated satisfactorily in any other way. A number of well-equipped hydraulic laboratories have been established for this specific purpose, particularly in Germany.

We have been much slower in this country to take advantage of this method. It is only during the past decade that a few laboratories in our engineering colleges have developed the method of model-tests in hydraulic problems and have begun to convince practical engineers that the method when properly applied will give correct results.

The first hydraulic laboratory in the United States which will be comparable in size and equipment with the best foreign laboratories is the National Hydraulic Laboratory now under construction at the Bureau of Standards. The purpose of this laboratory is to determine fundamental data useful in hydraulic engineering, to make tests of model hydraulic structures, and to test and develop hydraulic instruments. It is expected that the laboratory will be ready for operation early in the summer of 1932.

U. S. Bureau of Standards,
Washington, D. C.

A NEED FOR CLOSER COOPERATION AMONG STUDENTS OF STREAM-WORK

W. W. Rubey

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I feel very presumptuous in coming before this group with any suggestions of what might be done in the study of stream-dynamics. Nevertheless, I also feel very keenly that a frank recognition of the limitations of present knowledge in this bject would do much to stimulate observation and study; and I believe that the Section of Hydrology may afford a medium for the coordination of work now being done in several different fields.

No doubt, the name students of stream-work might properly be applied to a great many individuals interested in streams, but those to whom these remarks are particularly addressed are the hydraulic engineers, the laboratory physicists, and the geologists.

It is as a geologist that I venture to speak--one who is interested in streams as agents which transport and deposit sediment and as agents which also fashion landforms such as valleys, hills, and plains. In these two fields of sedimentation and physiography, as they are called, geologists are expected to interpret the work and history of ancient streams. It is obvious, therefore, that geologists have a very real interest in the principles of stream-work. To know what streams of the past have done, it is necessary--or at least highly desirable--to know what present-day streams are doing.

It seems to me quite likely that hydraulic engineers have much the same need as geologists for a fairly exact knowledge of the fundamentals that govern the behavior of streams--past, present, and future. In order to utilize or to control present-day rivers they should be able to predict just what these streams will do at any time in the future if certain conditions are changed in a specified manner. In general, the engineers are more interested in the immediate effects and the geologists in the ultimate effects of these changes, but it seems clear that to both of them a knowledge of the laws of stream-dynamics is of vital importance.

These fundamental principles of stream-work are by no means simple. The problem involves a great many independent and dependent variables, and no quantitative relationships of anything like general application have yet been formulated. To the geologists, the most valuable guide to the behavior of streams yet proposed has been the qualitative concept of dynamic equilibrium of stream-channels, which was elaborated by G. K. Gilbert more than 50 years ago. The stream is conceived primarily as a channel-maker or as a dynamic system which, either by scouring its bed or by depositing its load of sediment, tends always to make for itself a channel exactly adjusted to the work that must be done.

This concept has been so exceedingly useful in the interpretation of ancient and recent streams that geologists have been inclined to accept it as the whole story. However, it is noteworthy that Gilbert himself was not content with a priori deductions from this concept and one of his last papers, published in 1914, was an attempt to solve by extensive laboratory experiments some of the more involved questions to which the qualitative concept gives only ambiguous or even contradictory answers.

My own realization of the uncertainty of our knowledge of the principles of stream-work came when I noticed the marked differences of opinion about the origin of the meanders or systematic bends found in many alluvial streams. There seems to be reasonable agreement about the general mechanism by which these meanders are formed, but not about the conditions which, in the final analysis, cause the meandering habit. According to one group, composed chiefly of geologists, meanders are formed in streams which flow so feebly that the current is readily deflected against one bank or the other by minor obstructions in the channel. According to another group, which includes some geologists and a number of hydraulic engineers, meanders are formed in streams that flow too swiftly for their channels; the slope or gradient is too steep for the load that is being carried--hence the stream cuts its bank sidewise and thereby lengthens its channel and flattens its slope.

There are other interpretations also, but these two will serve to illustrate the point I wish to make. It is possible that both of these two explanations are right. If so, meandering may be the result of two diametrically opposite conditions, and it is then difficult to understand why all streams do not meander throughout their entire courses. Furthermore, if both interpretations are correct, what may we safely conclude about the historical significance of streams that have meandered at some time in the past? Or what valid predictions can be made about the effect of certain artificial changes upon streams that are meandering today?

So far as I can learn, this particular problem has never been adequately studied. Are the present meandering streams fully loaded or are they underloaded with debris? Are most of them building up or cutting down their floodplains? Between the times of

periodic cut-offs, does the slope gradually become flatter as the curves grow and the river-course lengthens? Or, instead, does the lengthening river build up its natural levees so as to maintain or even steepen the original slope? And is the volume of sediment deposited on the floodplain greater or less than the volume of alluvium displaced during the same period by the lengthened channel?

Data that bear closely but not directly upon these questions may be found in the detailed river-surveys that have been made by the United States Corps of Engineers and the Mississippi River Commission and also in the investigations of engineering models set up in the hydraulic laboratories of Europe and this country. But questions such as these were perhaps not clearly recognized when the surveys and the models were prepared, and the additional observations that might have afforded the critical information apparently were not made.

These are some of the many questions that may be asked about meandering streams, but any one of several other problems might just as well have been chosen. For example, it is a matter of the most fundamental importance in the practical matter of the control and improvement of rivers and in the theory of the development of landforms to know just what is the effect of a pre-existent slope upon a later slope of equilibrium. If the slope of a stream should be steepened without appreciably changing the volume of water or the load of sediment (say, by artificial straightening of a crooked river), will the new stream-channel eventually return to its original slope or will it adjust itself to the steepened slope by changing the load or the hydraulic radius or what? Or, to ask the same question in geologic instead of engineering terms, if a region should be tilted by earth-movements without appreciably changing the volume or the load of the streams in the region, will these streams proceed to cut their new channels to the original slope or will they adjust themselves to some intermediate slope, and if so, by changes of what kind? Despite the really fundamental importance of this problem, no effort seems to have been made, since Gilbert's suggestive but inconclusive laboratory experiments, to attack the problem experimentally or to collate the field-evidence that bears upon it.

I believe that a national committee such as this newly organized Section of Hydrology, including as it does representatives from many branches of science, may serve a real need by bringing into closer contact those who have approached problems of this sort from very different angles and by thus arousing a more general interest in fundamental questions of stream-work.

If such a policy were adopted of encouraging studies in this neglected borderline field, there would be need for cooperation from all who are interested enough to contribute. Observation of each of the many different types of streams and analytic descriptions of their differences of behavior would afford some of the data that are needed. Somewhat sporadic studies of this sort have been made by geologists and others, but such studies, to attain their maximum usefulness, should be systematically planned and comprehensively carried out.

A second and a most important class of observations are the exact measurements of natural streams. To know what actually is happening to present-day streams, we must know their seasonal and annual fluctuations of discharge and their changes of velocity, slope, load, and channel cross-section. In particular, we need to have measurements of the streams at flood or bank-full stages, for it is then that most of the stream's work on its channel is being done. Much excellent measurement of this sort has been made in the course of routine river-surveys, but there is still need for many systematic studies--continued over a period of years--along selected streams and for summaries of the data already published. Most of these quantitative studies will have to be made by the engineers, but the geologists can be of service in determining the character of the rocks that make up the stream-bed and the nature of the sediment that is being transported and deposited. The geologist will also be needed to decipher the history of the different streams, for this must be untangled before it is possible to understand the complex conditions under which the streams now flow.

Finally, the third class of observations by which the knowledge of stream-dynamics may be advanced are studies of artificial canals and laboratory models, for in them many of the complex variables of nature may be at least partially controlled.

A small group of British engineers in India, Burma, and the Sudan are now making valuable contributions by their studies of the conditions of stability in irrigation-canals. The older hydraulic laboratories seem to have been kept busy upon purely technical engineering problems, but the facilities soon to become available in this country, which we have just heard described, offer opportunities for the solution of many of the fundamental problems that still confront the engineers and the geologists.

U. S. Geological Survey,
Washington, D. C.

INVESTIGATIONS IN PROGRESS IN HYDROLOGIC LABORATORIES

Arthur M. Piper

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The investigations of which I shall speak deal with the occurrence and movement of water in the materials of the Earth's crust and are concerned with such fundamental properties of the materials as physical constitution, porosity, permeability, water-yielding capacity, and water-retaining capacity. The investigations are also concerned with the factors that control those properties and with the relation of those properties to one another and to many problems of hydrology, engineering, and agriculture.

Investigations of the fundamental laws involved in the hydrologic properties of materials are being carried on at Harvard University by H. J. Fraser in the Department of Economic Geology, and by Professor Fair in the Department of Sanitary Engineering, at the California Institute of Technology by Louis C. Hill, and at the University of California by W. C. Lowdermilk.

Fraser's investigation, which has been in progress about two years and a half, has comprised laboratory- and field-studies of porosity and permeability in relation to processes of deposition and of cementation in sediments. The relation between porosity and size of grain, uniformity of size of grain, proportion of different grain-sizes, and shape of grain was determined on artificial materials composed of small spheres and of screened sand fractions. The relations between permeability and water-temperature, hydraulic gradient, porosity, size of grain, uniformity in size of grain, and stratification were determined only on artificial materials composed of spherical grains. Measurements of the porosity of sand and gravel in place were then made along the rivers and beaches of New England to determine the action of waves and currents in arranging the grains of a sediment. The report covering Fraser's investigations is now being prepared.

Fair is conducting an experimental study of the permeability of filter-sands to amplify the previous work of A. Hazen. To this end he has prepared artificial sand-samples of known grain-size and uniformity-coefficient and is measuring their permeabilities at different hydraulic gradients. Tentative results indicate that for the range of grain-sizes studied, Hazen's "ten per cent size" is the true effective size. Hill's investigation at the California Institute of Technology covers a similar field.

Lowdermilk seeks to establish the relations between intensity and duration of rainfall and runoff to the character and amount of the vegetal cover, the slope of the land-surface, and the rate of rainfall-penetration into the soil. His investigation is being conducted out of doors with natural rainfall and artificial sprinkling.

In the past year the hydrologic laboratory of the United States Geological Survey in Washington has been engaged chiefly in direct measurements of mechanical analysis, porosity, permeability, and moisture-equivalent of natural water-bearing materials. Both consolidated sand-stone and unconsolidated materials have been tested, the unconsolidated material being repacked in the laboratory to field-density. Some modifications of technique have been made.

An investigation of the relation of the several hydrologic properties of a material to its mechanical analysis is being conducted by Messrs. Rollin Eckis and

P. B. K. Gross at a new laboratory of the California Division of Water Resources at Pomona College, Claremont. The mechanical analysis of the material is made and expressed in terms of mean size and of Wentworth's ratio of deviation (C. K. Wentworth, Method of computing mechanical composition types in sediments. Bull. Geol. Soc. Amer., v. 40, 777-785, 1929). The specific retention and specific yield of the material are determined by saturation and drainage of undisturbed samples. The numerical values of these properties are being plotted against the mean size, ratio of deviation, and porosity, in the belief that ultimately curves will be derived from which the specific yield and specific retention of a buried water-bearing material may be read if the mechanical analysis of that material is known from well-cuttings.

The relations of the hydrologic properties of materials to engineering problems are being studied by C. H. Lee in his private hydrologic laboratory at San Francisco. At this laboratory especial attention is being given to methods of collecting samples without disturbing the natural arrangement of particles or changing the moisture-content, so that the measured properties may be applied with surety in the analysis of engineering problems. The routine examination of a material consists of making a mechanical analysis and measuring the porosity, permeability, compressibility, plastic and shrinkage limits, plastic index, and shrinkage ratio. The Bouyoucos method (G. J. Bouyoucos, The hydrometer as a new and rapid method for determining the colloid content of soils. Soil Science, v. 23, 319-330, 1927; Making mechanical analyses of soils in 16 minutes, Soil Science, v. 25, 473-480, 1928) of mechanical analysis of silt and clay has been modified by the determination of coefficients to reduce the hydrometer-readings to true average density of the silt-suspension. It has been found that the friable materials--such as gravel, sand, and silt--are essentially rigid under compression and are essentially constant in permeability. On the other hand, the materials that contain clay are plastic and vary widely in permeability according to the degree of compaction, which in turn may depend upon the load of overlying material or upon the drying and consequent shrinkage of a saturated material. In the past year an inexpensive but effective method has been devised for reducing the leakage from reservoirs in sedimentary beds by coating their bottoms with inorganic material of colloid-size.

Many laboratories not engaged primarily in the investigation of hydrologic problems are gathering base-data that are very useful to the hydrologist. Among these are the sub-grade laboratory of the United States Bureau of Public Roads, Washington, and the laboratories that control the studies of soil-moisture, transpiration, and soil-erosion that are being made at many of the agricultural experiment stations.

There is a great need of coordination of effort between investigators of hydrologic problems, for the purpose of devising more effective and precise laboratory technique. Some of the accepted laws relating the fundamental hydrologic properties of materials to one another have been studied only within narrow limits and should be verified over a wider range of conditions. Much more work should be done on natural materials sampled in such a way that the arrangement of grains is not disturbed. The results of such tests should be compared with tests of materials repacked in the laboratory after the conventional technique.

U. S. Geological Survey,
Washington, D. C.

SOME RECENT STUDIES IN EVAPORATION

C. V. Theis

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During the past few years several important contributions to the study of evaporation from open water-surfaces have been made. Each has applications to which it is peculiarly adapted, and each has its limitations.

The first of these new studies is that upon the Great Lakes initiated by Hayford many years ago, completed by Folse, and described in Publication 400 of the Carnegie Institution of Washington in 1929. In this work data concerning evaporation from the

Great Lakes were thoroughly studied by the methods of statistical analysis. The study deals, therefore, with evaporation from very large bodies of water; the Great Lakes were taken as the evaporation-pan. Folse develops an equation giving the evaporation from a large water-surface in terms of the deficit in vapor-pressure (saturated vapor-pressure corresponding to air-temperature minus existing vapor-pressure), and the wind-travel. All data used are those obtainable from regular Weather Bureau statistics. Folse states that the formula is applicable to all large water-surfaces. If so, it will be exceedingly valuable. It undoubtedly represents the utmost accuracy that may be attained by empirical methods applied to evaporation-phenomena connected with any one large body of water.

Very extensive work has been done upon the subject by the Scripps Institution of Oceanography and the California Institute of Technology. This work has been summarized by McEwen (G. F. McEwen, Results of evaporation studies conducted by the Scripps Institution of Oceanography and the California Institute of Technology. Bull. Scripps Inst., Tech. Ser., v. 2, 401-16, 1930), and a discussion of the work from the engineer's standpoint has been given by Richardson (Burt Richardson, Evaporation as a function of insolation. Proc. Amer. Soc. Civ. Eng., v. 56, 945-960, 1930). This work is based upon heat-equations, in which the incoming energy from solar- and sky-radiation is balanced against all heat-losses from the evaporation-pan. If accurate measurements of the results of all these processes can be obtained, the evaporation can, of course, be computed. Simplifications of the ideally correct equations have been made, enabling them to be used in localities where measurements of the several factors are not available. The correspondence of evaporation computed by this formula with that actually observed at different localities has been shown. However, the simplified equation apparently will not hold for many of the evaporation-stations maintained by the Weather Bureau. This method will probably be of greatest value in computing the evaporation from large bodies of water, where the nature of the problem warrants the actual observation of all the factors involved.

In an attempt to predict the evaporation from a projected reservoir in a region in which no evaporation-measurements had been made, the writer was led to a study of some of the Weather Bureau data on evaporation. This led to an attempt to combine the effects of solar-radiation and deficit in vapor-pressure. The expressions set up were rather crude but yielded results that corresponded very closely with the observed evaporation from standard pans on a monthly basis.

It was considered that over a period of some duration, say, one month, the average rate of evaporation might correspond to the product of the average insolation and the average deficit in vapor-pressure, as modified by the evaporation from the pan itself. Then if E' = the evaporation from the pan into one column of air of small cross-section, at any instant during its passage over the pan, R = solar- and sky-insolation, D = dryness of air or vapor-pressure deficit at air-temperature, D' = instantaneous dryness at any time at the base of the column of air, decreasing with the passage of the air over the pan due to the evaporation from the pan, t = time the column of air has been in contact with the water, and k = constant

$$dE'/dt = kRD'$$

Some expression must be introduced in place of D' in order to make this expression usable. D' evidently will decrease during the travel of the air-column across the pan. The decrease will be a function of the amount of evaporation, or E'. Some of the vapor will diffuse from the air-water contact during this time. Under certain assumptions, the more rapid the rate of evaporation the less chance of diffusion, so that this "wetting effect" will increase with the rate of evaporation, or dE'/dt. It was assumed, as an approximation and in order to give an equation that could be easily integrated, that this wetting effect was proportional to the product of the total evaporation and the rate of evaporation. In symbols

$$dE'/dt = kR\,[D - c'E'(dE'/dt)]$$

where c' is a second constant of proportionality. This equation integrates into the following:

$$E = (1/kRc')\,(\sqrt{2c'k^2R^2Dt + 1} - 1)$$

where E = total amount of evaporation into one column of air during its passage. Now t = m/w, where m = length of travel across pan and w = wind-velocity. Substituting, we have

$$E = (1/kRo')\,[\sqrt{(2c'k^2R^2Dm + 1)/w} - 1]$$

In the course of a month the evaporation would be the sum of the evaporation into all the columns of air which had passed the pan. If a month is taken as the unit by which w is measured the number of columns is proportional to w. Reducing the evaporation to terms of depth by dividing by m, we get

$$E_{mo} = [w/(mkRo')]\,[\sqrt{(2c'k^2R^2Dm + 1)/w} - 1]$$

If we confine our formula to standard circular-pans, m will be constant and may be absorbed in c', giving a combined constant, c. When E is measured in inches, w in miles per month (measured at the pan), D in inches of mercury. and R in calories per square centimeter per day (average), the commonly used units, the equation for monthly evaporation may be written

$$E_{mo} = [w/(kRo)]\,[\sqrt{(2c\,k^2R^2D + 1)/10w} + 1 - 1]$$

in which k and c are both near to unity in value. D as used herein is the value obtained by the formula

$$D = V\,[1 - (H_m + 2H_n + H_e)/4]$$

where V = vapor-tension corresponding to mean monthly temperature, H_m = relative humidity determined in the early morning, H_n = relative humidity determined at noon, and H_e = relative humidity determined in late afternoon.

It should be emphasized that both the initial equation and the expression for the wetting-effect due to evaporation from the pan are pure assumptions and may have no theoretical value. The derivation has been introduced only to show the assumptions implied in the unusual type of evaporation-formula used. The justification of the equation must be purely empirical.

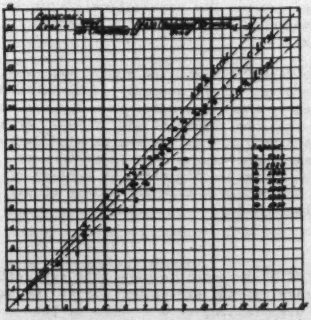

Fig. 1--Observed versus computed monthly evaporation, inches per month, at Lincoln, Nebraska, 1924-30

Figure 1 shows the application of this formula to Lincoln, Nebraska, during the seven years from 1924 to 1930. It will be observed that most of the errors, except those of 1930, fall well within 10 per cent. The year 1930 was apparently anomalous. It should be pointed out that the error during this year was nearly constant at about 20 per cent. No explanation for the discrepancy has so far been found. In these computations k has been taken as 1, and c as 1.19. Table 1 gives the data and results of computations for the year 1926.

The application of the same type of formula to a locality at which there are no direct observations of the insolation is somewhat more complex. The insolation here must be computed. The computations recorded in this paper were based on values of radiation computed from the solar-factors given in the Smithsonian Meteorological Tables. A slightly simpler method would use as a base the values of the radiation incident on the exterior of the atmosphere. (For a table of these values see Burt Richardson, Evaporation as a function of insolation, Proc. Amer. Soc. Civ. Eng., v. 56, 958, 1930.) If F represents the solar factor, S the fraction of possible sunshine received, and R' the (computed) radiation, the following equation seems to be approximately true

$$R' = 960F\,(S + 1)/2 \text{ calories/cm}^2\text{/day}$$

Table 1--Data and computed evaporation, Lincoln, Nebraska, 1926, using formula

$$E_{mo} = [w/1.19R]\,[\sqrt{2.38\,R^2D/10\,/w + 1} - 1]$$

Month	Obs'd evap'n	Solar- and sky-rad'n, R	Wind at pan, w	Mean month temp.	Relative humidity			Computed value, D	Computed evap'n, E
					7 a.m.	Noon	7 p.m.		
	inches	cal/cm²/d	mi/month	°F	per cent				inches
April	7.005	485	3,634	49.5	66	36	36	0.20	6.33
May	9.652	535	4,221	66.2	72	46	46	0.32	9.89
June	10.183	563	2,952	70.9	70	43	46	0.38	9.83
July	11.122	550	2,699	78.6	75	47	47	0.46	11.01
August	9.746	519	2,408	77.6	81	45	49	0.42	9.75
September	5.070	514	3,212	64.6	85	65	71	0.19	4.80
October	3.942	285	2,410	54.8	76	52	58	0.19	4.23

It will be desirable to introduce the value R'', expressing the value of R' for $S = 1.00$; $R'' = 960$ F.

In studying the evaporation-record at Yuma, Arizona (Citrus station), which, unlike the Lincoln record, covered all months in the year, it was found that the evaporation for the winter months computed according to the formula given above consistently exceeded that observed. Therefore, the formula was adapted to consider the varying length of day throughout the year. The quantity R'' was reduced for each month to the value it would have if the days of the month were as long as those of June, and the resulting computed evaporation was reduced by the ratio of the length of day in that particular month to the length of day in June, and further reduced according to the cloudiness. In symbols, if L expresses the ratio, at a given latitude, of the average length of day in a particular month to the average length of day in June, then

$$E_{mo} = [(1 + S)/2]L\,[(w/c)(L/kR'')]\,[\sqrt{[(2cD/10)/w]\,[kR''/L]^2 + 1} - 1]$$

In the computations following k was taken as 0.895 and c as 0.9.

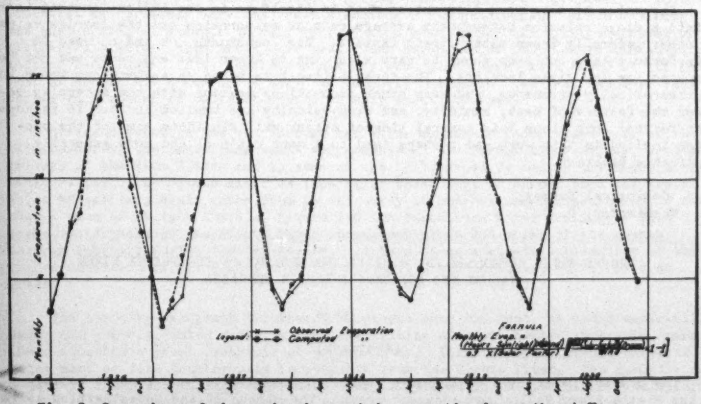

Fig. 2--Comparison of observed and computed evaporation by months at Yuma, Arizona (Citrus station), 1926-30

Figure 2 exhibits a comparison of the computed and observed evaporation at Yuma, Arizona, (Citrus station) for the period 1926-1930, and Table 2 gives data and results at Yuma for the year 1929. The dryness-factor, D, is that resulting from data taken at the Weather Bureau station at Yuma, a few miles from the evaporation-pan. The average monthly error for the period of computation (58 months) was under 5 per cent; the maximum error was 12.5 per cent.

Table 2--Data and computed evaporation at Yuma, Arizona (Citrus station), 1929

Mo.	Obs'd evap'n	Wind, w	Mean month temp.	Relative humidity			Computed value, D	Possible sunshine	Rel. length day, L	0.895 R"/L	Computed evap'n, E
				6 a.m.	Noon	6 p.m.					
	inches	mi/month	°F	per cent				per cent			inches
Jan.	3.980	1,335	51.6	56	28	29	0.25	86	0.748	392	3.90
Feb.	5.484	1,749	55.0	47	20	19	0.32	91	0.775	469	5.75
Mar.	8.690	2,317	63.0	50	20	17	0.43	91	0.844	535	8.72
Apr.	11.017	2,442	67.2	53	19	16	0.49	93	0.914	583	10.89
May	15.389	2,119	78.2	49	13	11	0.76	98	0.972	596	14.80
June	16.419	2,320	84.5	57	16	14	0.88	98	1.00	600	17.30
July	16.741	2,312	92.0	64	28	27	0.95	90	0.990	595	17.10
Aug.	13.865	1,868	91.9	67	35	34	0.85	83	0.938	585	13.40
Sep.	10.254	1,676	84.0	74	36	33	0.65	90	0.870	547	10.37
Oct.	9.053	1,466	75.9	61	24	28	0.60	97	0.796	486	8.65
Nov.	6.234	1,497	60.6	40	16	23	0.41	98	0.715	430	6.43
Dec.	4.907	1,306	59.2	46	22	34	0.35	95	0.708	380	4.80
Year	122.033	.....	....	..	..	..	....	..	.....	...	122.11

The value of this work lies not so much in itself as in the indication that there exists a close relation between the average rate of evaporation and the average values of other generally known meteorologic factors. The "constants," k and c, used in this formula have not been shown to vary according to known laws and hence can not be computed for any given locality. The formula itself is based on assumptions known to be theoretically erroneous, and many other assumptions dealing with the interplay between the factors of heat, humidity, and wind-velocity are implied in it. It is hoped that further work along this general line of attack will elucidate some of the problems implied in this work and perhaps lead to a more rational and more generally applicable equation.

U. S. Geological Survey,
Washington, D. C.

GROUND-WATER HYDROLOGY AND PLEISTOCENE GEOLOGY OF THE PLATTE RIVER VALLEY AND ADJACENT AREAS IN NEBRASKA

A. L. Lugn

(Abstract)

The present paper is a preliminary report on ground-water and general geology of the Platte River Valley and adjacent areas. The object of the investigation is to obtain information on the configuration of the water-table, the direction of movement of underground-water, the distribution, slope, thicknesses, and character of water-bearing sands and gravels, and quantity of sub-surface water.

The surface of eastern Nebraska is underlain with Pleistocene deposits, resting on the Pliocene peneplain, in this order from below up: Sub-drift or sub-Nebraskan

gravel 20 to 100 feet thick; Nebraskan till and gumbotil up to 100 feet thick; Kansan till and gumbotil up to 80 feet thick; red Loveland gravel, sand, and loess-clay 0 to 30 or more feet thick; yellow loess clay mostly of Peorian age 30 to 70 feet thick. The Kansan glacial-till when present rests unconformably on the Nebraskan till and gumbotil. The gumbotil (Nebraskan) occurs only as remnants. Likewise, erosion-unconformities separate the Loveland deposits from the underlying Kansan till and gumbotil (where present) and the yellow (Peorian) loess from the Loveland. It is also significant that the Nebraskan till is thicker and more extensive and better developed in Nebraska than the Kansan drift. The Nebraskan stage is most appropriately named.

The Loess Plains of south central Nebraska, an area of about 5,000 square miles west of the glacial-till covered area, are underlain by the yellow (Peorian) loess and Loveland deposits, which increase in total thickness westward to a maximum of about 300 feet, and under these formations are thick and extensive beds of gravel, sand, silt, and clay which represent the fluvioglacial outwash from the ice-sheets and the drift-plains to the eastward and the contemporary inwash of sediment-ladened streams from the west and northwest. These deposits are comparatively uniform and both extensive and persistent and can be correlated with contemporaneous glacial formations. The bed of sand and gravel which lies directly under the Loveland ranges in thickness from about 40 feet to 100 feet and is believed to be for the most part of Kansan age, being the outwash from the melting Kansan ice and the contemporary inwash from other directions. A persistent bed of silt and clay 8 to 30 feet thick separates this upper or first-water "sand" formation from the underlying or second-water "gravel." This clay bed is believed to represent the lull in sedimentation during the Aftonian stage. There are a few places where it is not present and there are also a few localities where other thin local lenses of clay are encountered at other horizons but mainly within the upper-water sands. The lower Pleistocene gravel-sand formation varies from about 50 to 150 feet thick and is thought to be Nebraskan in age.

The Pleistocene formations all dip consistently to the southeast and rest on the Pliocene peneplain developed on Carboniferous, Cretaceous, and in the west Tertiary bed-rocks. The bed-rock surface is not without some relief as there is some evidence of low hills and ridges, in a few localities, on the otherwise featureless plain. Such hills and remnant bed-rock ridges trend from north-northwest to south-southeast and probably mark the Pre-Pleistocene drainage-divides. Shale bed-rock was encountered at a depth of only 85 feet at a point about six miles southwest of Giltner; a similar "high point" has been found northeast of Clay Center and still another near Edgar. Blue bed-rock shale has been encountered at a depth of 132 feet west of Norman and a few miles north of Campbell "magnesia" bed-rock has been reported in a number of wells at depths of only about 100 feet.

Stream-dissection has cut through the thick mantle of loess clays west of the till-border to the underlying sands and gravels in the Platte River valley, in the valleys of the Blue Rivers and in some of the tributaries to and in the Republican River valley. The Platte River is flowing on these beds of porous sand and gravel which effectively drain water from it and carry it underground southeastward to discharge much of it into the Blue Rivers and the Republican River drainage. This explains the dryness of the Platte River throughout about 200 miles of its course through Nebraska during the dry season. It is also an adequate explanation of the graded condition of the Platte with its relatively high gradient for a river at grade.

The porosity and great thickness, in places over 200 feet, of these water-filled sands and gravels, which underlie the Loess Plains of south central Nebraska, make these deposits a great reservoir of ground-water. This supply of ground-water is being more or less continuously replenished from the Platte River. The quantity of water, in transient storage under this area, if placed in an open basin, would form a lake 30 feet deep covering an area of 4,000 square miles or a little over 75 million acre-feet.

Present wells and equipment have been adequate to supply all the water needed in cities and towns and for domestic farm use. No place in this great area should ever lack for water, either in quantity or quality and purity. So far very little

has been done to utilize this great underground-supply for irrigation. However, at one place several hundred acres are now being irrigated with deep-well water and every indication points to success for this project. Expansion in the use of water in this way will come as more efficient equipment is perfected for raising water from depths ranging from 60 to 150 feet. Cheap electric power should eventually find a ready market in this area for deep-well pumping. Crude-oil engines might be used economically. Both of these types of power can be applied very effectively to the turbine-type of pump for lifting water from almost any depth. Windmills might be built to raise fairly large quantities of water from deep wells but little has been done along this line on a large scale.

No area in the country has any richer or potentially more productive soil than the Loess Plains of south central Nebraska. The only thing lacking is an adequate amount of rainfall. Evidence now in hand on deep-well irrigation, even at high cost, indicates that the productiveness of the soil can be increased two to three hundred per cent by this method of supplementing the natural water-supply, and at a cost that will still bring a large return in increased profits to the farmer. When means that are now available and cheaper means that may be developed are utilized to draw on this great resource of water the basic wealth of more than 4,000 square miles of this State and some hundreds of thousands of its inhabitants will be greatly increased.

University of Nebraska,
Lincoln, Nebraska

WORK ON RUNOFF-DATA

C. F. Merriam

(Informal communication)

The speaker expressed his appreciation of the invitation to be present at this meeting, particularly to attend with H. W. Lowy, Hydrographic Engineer at the Holtwood Plant of the Pennsylvania Water and Power Company, since Mr. Lowy had done pioneer work in stream-gaging by means of powerhouse-records. It was he who called his Company's attention to the importance of keeping accurate records, and has demonstrated that valuable information could be derived. Through his initiative the Company is in a position to take its present active interest in hydrology.

He also expressed his appreciation for the cooperation which his Company had received on several occasions from the United States Geological Survey and expressed the desire to hold up their end of the burden by an equal willingness to cooperate with the Government officials. Consequently considerable time had been devoted to certain studies which may be of interest to hydrologists.

Through his connection with the Subcommittee of Forecasting Water-Supply of the National Electric Light Association, of which A. Streiff is Chairman, attention had been centered upon deriving tests for inconsistency of past records, both for rainfall and runoff. Results of these studies have been published as Publication No. 115 of the National Electric Light Association. (Copies of this may be secured by application to Mr. E. S. Baker, Editor of Publications, 420 Lexington Avenue, New York City.) Preliminary studies dealing particularly with rainfall and runoff in the Susquehanna Valley are included in the Reports of the Hydraulic Power Committee of the Pennsylvania Electric Association for 1928-1929-1930 (although now out of print, copies are filed in the Engineering Societies Library, 29 West 39th Street, New York City).

It was felt that there was great danger in building up of systems of long-range forecasting based upon defective data, and for this reason tests were developed and proposed for determining to what extent past records were defective, and suggestions were made for the correction of imperfect data.

These tests are mathematically very simple, but have been shown to be effective in bringing to light faults in past records. It was stated that consistent rainfall-

records for any length of time are, as a matter of fact, very exceptional. Runoff-records have been found as a rule to be of higher quality.

Since the publication of the above-mentioned reports, the methods proposed have been applied by the United States Engineers in connection with the Susquehanna River studies, and it has been demonstrated that very good estimates of the mean annual runoff, having in all probability a high degree of accuracy, had been derived from comparatively few months of observation during a particularly unfavorable period of extreme drought. Furthermore, estimates of mean annual rainfall, which appear to be quite in line with those of neighboring gages, have been made based on very few years of observation. It was believed that an opportunity has been opened up for securing very acceptable estimates of mean runoff and rainfall from short periods of observation, and that these methods may be of interest to those who are obliged to depend upon short-term records.

His Company is continuing the study of analytical methods for deriving useful information from meteorological and hydrographic data, and has already found a simple application for the method of least-squares, which may be very easily applied in determining mean values.

Pennsylvania Water and Power Company,
Baltimore, Maryland

FORMATION OF THE SECTION OF HYDROLOGY OF THE AMERICAN GEOPHYSICAL UNION

O. E. Meinzer

The American Geophysical Union is the American National Committee of the International Geodetic and Geophysical Union, and its executive committee is the Committee on Geophysics of the National Research Council. The American Geophysical Union is divided into several sections, following the plan of organization of the International Union. At the annual meeting in May 1930 a Section of Hydrology was authorized to conform to the Section of Scientific Hydrology of the International Union.

A meeting of the members of the Union who expressed their desire to be affiliated with the new Section of Hydrology was held at the National Research Council in Washington, D. C., on November 15, 1930. At this meeting the following officers were elected: Chairman, O. E. Meinzer; Vice-Chairman, R. E. Horton; Secretary, H. M. Eaton. An executive committee was created consisting of the three officers together with such other members as the Chairman might select. Subsequently M. C. Grover and W. W. McLaughlin were added to the committee.

The need has long been felt for some organization that will establish contact between the many widely scattered workers in the various fields of hydrology in the United States, coordinate their efforts, and bring them into better contact with the hydrologic work that is being done in other countries. The Section of Hydrology affords an ideal opportunity for supplying this need, provided an adequate organization for the purpose can be planned and can be put into effect through the hearty cooperation of many workers. With this problem in mind, the Executive Committee is working on a plan to create a number of permanent committees, each of which will cover one or more fields of the subject of hydrology and will submit a report once a year. These reports are to be presented at the annual meetings and subsequently published in the Transactions of the Union.

On March 6, 1931, the Executive Committee of the Section of Hydrology sent a circular letter to numerous American workers in hydrology in which the plan of organization was presented. It was desired to reach all research workers in hydrology in the United States but doubtless many who should have received the circular letter were inadvertently overlooked. The committee would, however, be glad to hear from everyone who is engaged or interested in research in any field of hydrology. The following is quoted from the circular letter:

"Each committee is to undertake (a) to stimulate research within its field; (b) obtain the preparation of papers of such a character as to advance the field of hydrology to which it is devoted; (c) secure coordination of workers and correlation of the results of research in different branches of its field; (d) facilitate dissemination of literature in its field; and (e) make an annual report which, so far as practicable, is to be presented at the annual meeting of the Union and published in its Transactions. Each report is to be a concise but comprehensive statement of the work that has been done in the field covered by the committee, the books and papers that have been published, the work that has been in progress during the year, and the outstanding achievements andproblems, together with recommendations as to the nature of future work and the objectives to be attained. The reports should cover primarily the work in the United States but also, so far as practicable, the important work that is being done in other countries.

"Each committee should consist of men engaged in research work or in close touch with the research work that is being done in the field which it covers. In order to cover the entire field, the members of a committee should represent different parts of the country, different phases of the work, and different organizations or groups of workers. Thus each member may be expected to make a contribution on the work with which he is especially familiar. In order to make the plan successful it will be necessary to make it representative of the hydrologic work in the entire country. In no case is the Section, or any of its committees, to supplant or compete with any existing organization that is concerned with hydrologic work. The purpose of the Section is to establish helpful relations between all workers and groups of workers in hydrology.

"The scope of the Section's activities will not necessarily include everything that might be included within the science of hydrology. As the Union includes a Section of Meteorology and a Section of Oceanography, it would seem that the work of the Section of Hydrology should relate chiefly to the study of the natural waters from their precipitation upon the land to their discharge into the ocean. It has been suggested that the entire subject of the mechanical and chemical activity of the natural waters (exclusive of the ocean), which is obviously covered by the above definition, should be included in the work of the Section, although this part of the subject is somewhat on the fringe of hydrology and includes much of the subjectmatter of geology. Similarly, the biology of the natural waters constitutes a large subject which is on the fringe of hydrology and need not be included in the work of the Section unless or until biologists and bacteriologists who are concerned wish to participate.

"Herewith is a suggested list of fields to be covered by the committees. In some cases it may be desirable to have two or more fields covered by one committee. It is not expected that all of the committees will be organized at once, but rather that committees will be organized as interest is expressed in the several fields and as workers and leadership are forthcoming. It will be the policy to make appointments on the committees regardless of whether the appointees are at present members of the Union, but it is expected that in the course of time elections to membership in the Union will be made from committee members who make the most valuable contributions.

"The Executive Committee desires very much to receive a letter from every scientist to whom this memorandum is sent. We wish to know your opinion in regard to the feasibility and advisability of organizing the work of the Section by means of the permanent committees; we would welcome constructive suggestions for any other plan of organization. What suggestions have you as to changes in the list of fields to be covered or the number of committees that should be created? Are there additional fields that should be covered? Please indicate the field of your own work and the committee or committees on which you are willing to serve.

Written replies were received from about 90 persons and oral responses from many more. These replies have furnished the Executive Committee with a large amount of very useful information. The great majority of those who replied expressed enthusiasm over the enterprise and offered to help in the work that is to be undertaken. Most of the replies contained constructive suggestions and some contained valuable criticisms. All have been given careful consideration, and in the aggregate they form a very valuable file of information and advice.

The following is a slightly modified list of suggested fields of hydrology that was submitted with the circular letter. It is obviously illogical and overlapping in some respects and is to be regarded as suggestive rather than authoritative or final.

Suggested fields of hydrology to be covered by permanent committees of the Section of Hydrology

(1) Distribution and intensity of precipitation
(2) Hydrology of snow (snow-surveys, evaporation of snow, melting of snow and its effects, prediction of stream-flow from snow-surveys)
(3) Hydrology of glaciers
(4) Evaporation from free water-surfaces and the fluctuation of lakes
(5) Transpiration and evaporation from soil (including their relation to ground-water levels and stream-flow)
(6) Soil-moisture (including frost-action and the dynamics of soil-moisture in land-slides, mud-flows, and subsidences)
(7) Absorption of rain, snow, and stream-waters, and the resulting fluctuations of the water-table
(8) Methods of measuring the flow of streams
(9) Runoff and its interpretation and prediction (including low stages produced by droughts)
(10) Floods and their expectancy
(11) Movement of water in the zone of saturation
(12) Hydrology of artesian basins
(13) Relation of fresh surface-waters and ground-waters to salt-waters
(14) Hydrology of limestone terranes
(15) Hydrology of hot springs, hydrologic work in connection with volcanology, and the hydrology of volcanic terranes
(16) Quantitative methods in ground-water hydrology
(17) Laboratory work in hydrology
(18) Hydrologic work in connection with the study of metalliferous deposits
(19) Hydrologic work in connection with petroleum investigations
(20) Dynamics of rivers, and their work in erosion, transportation, and deposition
(21) Dynamics of rain- and surface-waters in soil-erosion, transportation, and deposition
(22) Dynamics of waves and currents along shore-lines
(23) Chemical character and chemical work of surface- and ground-waters
(24) Biology of surface- and ground-waters
(25) Historical and prehistorical hydrology
(26) Bibliography of hydrology

The principal objective for the ensuing year is to make a complete survey of all hydrologic work of every sort that is in progress in the United States, and to have the results of this survey ready for presentation at the 1932 meeting of the Union and for publication in the Transactions of that meeting. It is not expected that anyone will devote a large amount of time to this work, but it is greatly desired that reports be received from a large number of workers giving concise but comprehensive and exact information in regard to their own work and the work of others with which they are familiar. Although it is the intention to organize committees, every one interested in any phase of the subject of hydrology, whether he is appointed on a committee or not, is invited to communicate to the Secretary (U. S. Bureau of Standards) pertinent information as to work that is being done by himself or his colaborers. Numerous national and regional societies, Federal and State governmental departments or bureaus, universities, and research institutions are concerned with certain phases of hydrology. Contact should be made with all of these organizations and reports should be obtained from them, giving precise information as to the nature and scope of their activities in hydrology. This can be accomplished only by the voluntary cooperation of many persons who are familiar with one or another of these organizations.

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